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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 395

Contribution from the Bureau of Plant Industry
WM. A. TAYLOR, Chief

Washington, D. C. PROFESSIONAL PAPER January 18, 1917

PEACH SCAB AND ITS CONTROL

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By

G. W. KEITT, formerly Scientific Assistant
Fruit-Disease Investigations

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PEACH SCAB AND ITS CONTROL.[1]

By G. W. KEITT,

Assistant Professor of Plant Pathology, University of Wisconsin; formerly Scientific Assistant, Fruit-Disease Investigations.

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INTRODUCTION.

Peach scab (*Cladosporium carpophilum* Thüm.) is a parasitic disease which affects the fruit, twigs, and leaves of the host (*Amygdalus persica*). It manifests itself on the fruit as small, circular, olivaceous to black spots, which frequently become confluent over considerable areas and seriously detract from the appearance, quality, and value of the marketable product. On the twigs and leaves it occasions less damage, producing small superficial injuries, which are described in detail later. In the United States, east of the Rocky Mountains, it occurs generally, and unless controlled it may cause serious financial

[1] The laboratory studies upon which this paper is based were conducted in field laboratories at Hart, Mich., in the season of 1911, at Cornelia, Ga., in the seasons of 1912 and 1913, and in the laboratory of plant pathology of the University of Wisconsin in the winters of 1911 to 1914 and the summer of 1914. The field work was carried on in cooperation with growers in commercial orchards at Hart, Mich., in 1911, and at Cornelia, Ga., in 1910, 1912, and 1913.

losses in practically all of the important peach-producing districts in this area.

The disease was first reported from Klosterneuberg, Austria, by Von Thümen (1877),[1] who observed its occurrence upon the fruit of the peach and briefly described the associated fungus as *Cladosporium carpophilum* sp. nov. The same author (1879, p. 13–15) emended his original description of the fungus and published notes concerning the occurrence, description, and economic importance of the malady. The disease received little further attention until its occurrence in America was reported by Arthur (1889, p. 5–8), who noted its prevalence in Indiana and described the fruit lesions and the associated fungus, citing the work of Von Thümen. Peach scab, however, was not unknown to American mycologists prior to this time, since the herbarium of the New York Botanical Garden and the Pathological Collections[2] of the Bureau of Plant Industry contain specimens collected by F. S. Earle, Cobden, Ill., 1881[3] (on fruit) and 1887[3,4] (on leaves), and by A. B. Langlois, Mississippi, 1886[3,4] (on fruit). Pammel (1892, p. 100) reported that Galloway, in unpublished notes, had recorded the occurrence of the "peach fungus" (*Cladosporium carpophilum*) on peach leaves. Halsted (1895, p. 329–330) described what he considered to be scab injury upon peach leaves. A study of his description and illustrations, however, makes it appear conclusive that he failed to differentiate true scab injury from other foliage troubles. Taft (1894, p. 57) reported the scab fungus as attacking fruits, leaves, and tender shoots of the peach. He gave no details, however, concerning the injury on twigs and leaves. Sturgis (1897) noted a fungus, which he reported as conforming morphologically to the description of *C. carpophilum*, associated with twig injuries of the peach, almond, and apricot. He concluded that the fungus was *C. carpophilum* and that it was the causal agent of the trouble. He reported, however, no cultural studies or infection experiments. Clinton (1904, p. 340–341) briefly described scab injuries on peach fruit, twigs, and leaves.

Selby (1898 and 1904), beginning in 1895, conducted an extensive series of peach-spraying experiments, from which he concluded that scab may be controlled by the use of Bordeaux mixture. A large number of similar tests have been made with Bordeaux mixture of various formulas and methods of preparation, but the toxicity of this fungicide to the foliage has prevented its coming into general use in the United States as a summer spray for peaches. Scott (1907 and

[1] Bibliographic notations in parentheses refer to "Literature cited," pp. 64–66.

[2] The writer wishes to express his indebtedness to the curators of these herbaria for their kindness in making these records available and in sending him material which enabled him to verify the identification of each of these collections.

[3] In the herbarium of the New York Botanical Garden, New York.

[4] In the Pathological Collections of the Bureau of Plant Industry, United States Department of Agriculture.

1908) obtained promising results from the use of self-boiled lime-sulphur for peach-scab control. The same author (1909) reported that this fungicide satisfactorily controlled the disease without objectionable foliage injury and recommended its use in commercial orchards. These results have been confirmed by Scott and Ayres (1910), Scott and Quaintance (1911), and other investigators.

Thus, while peach scab has received a considerable amount of attention from botanists and plant pathologists, the status of knowledge of the disease has remained fragmentary and incomplete. No attempt at a thoroughgoing study of the malady appears to have been undertaken, previous work having been confined chiefly to descriptions of *Cladosporium carpophilum* and of the injuries which it induces, to field observations, and to the empirical development of control measures. Consequently, the etiology of the disease has not been scientifically determined and the detailed life history of the causal organism in relation to pathogenesis and to control measures has remained obscure.

The purpose of the investigations reported in this bulletin has been to further the understanding of the nature, cause, development, and control of peach scab. Accordingly, the effort has been directed along four correlated major lines of study, viz, (1) the disease, (2) the causal organism, (3) the detailed life history of the causal organism in relation to pathogenesis, and (4) control measures.

Studies of the relationships of peach scab to similar diseases of other stone fruits have not been included in this problem, though such investigations are now under way. Consequently, only peach scab will be considered in this bulletin.

THE DISEASE.

GEOGRAPHIC DISTRIBUTION.

In order to supplement the available published data concerning the geographic distribution of peach scab in the United States, a brief questionnaire was recently sent to the authorities[1] of each State agricultural experiment station. The disease was reported from the following States: Alabama, Arkansas, California, Colorado, Connecticut, Delaware, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Massachusetts, Michigan, Mississippi, Missouri, Nebraska, New Hampshire, New Jersey, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, Rhode Island, South Carolina, Tennessee, Texas, Virginia, and West Virginia.

In foreign countries, scab appears to occur practically wherever the peach is grown intensively under normal conditions. However, since peach production abroad is relatively of much less importance

[1] The writer wishes to make grateful acknowledgment of his indebtedness to all who cooperated in compiling these data.

than in the United States, the disease has received only minor attention from foreign writers. Von Thümen (1877) reported its occurrence in Austria; Cobb (1894, p. 385–386), in Australia; Craig (1898, p. 40), in Canada; Oudemans (1901, p. 388), in Holland; Sorauer (1908, p. 252), in southern Europe; and Evans (1911, p. 696), in South Africa.

ECONOMIC IMPORTANCE.[1]

Badly scabbed fruit is seriously reduced in market value (1) by its unsightly appearance (Pl. I, figs. 1 and 2); (2) by its lack of uniformity in size, shape, and evenness of ripening; (3) by the cracking of individual or of confluent lesions (Pl. I, fig. 1, and Pl. II) and the consequent increment in destructive fungal and bacterial invasions—notably brown-rot (*Sclerotinia cinerea* (Bon.) Schröt.) (Pl. II, upper figure); and (4), in severe cases, by its impaired flavor. Further loss may be occasioned by the premature shedding or shriveling of fruits which are badly scabbed about the attachment of the peduncle.

Many writers have reported severe economic losses from peach scab. Selby (1904, p. 63) recorded heavy losses in Ohio. Rolfs (1909, p. 66) states—

> At least 60 per cent of the Elberta fruit on the station ground during the season of 1906 was ruined by this organism [*Cladosporium carpophilum*]. The loss was even greater on a number of other varieties.

Scott and Ayres (1910, p. 14) write—

> The damage done by this disease is apparently not fully realized by peach growers. Scab spots are so common on the peach that most of the eastern growers have come to take the disease as a matter of course and scarcely realize that their fruit is bringing 25 per cent less in the market than the same fruit free from scab would bring. * * * In many localities it practically prohibits the growing of certain varieties * * * and the growers have been obliged to confine their plantings of such late varieties as Bilyeu and Salway to the high ridges in order to avoid scab.

Scott and Quaintance (1911, p. 10–11) say—

> If the loss in the orchard and the reduction in market value are both considered, it seems evident that a loss of 10 per cent of the total value of the peach crop in the eastern United States is caused by peach scab.

In order to supplement the data from published records and personal observations, an inquiry concerning the economic importance of the disease in the various States was included in the questionnaire referred to on the preceding page. The answers showed a consensus of opinion that, unless controlled, the disease may occasion serious losses in practically every important peach-producing State east of the Rocky Mountains.

In formulating a more concrete conception of the economic importance of the disease, it is of interest to refer to the estimates of the latest census report [2] from which the data in Table I are taken.

---

[1] See estimates and notes by Mr. M. B. Waite, p. 45–46.

[2] Thirteenth Census of the United States . . . v. 5, Agriculture, 1909–10, p. 711, tab. 133, 1913.

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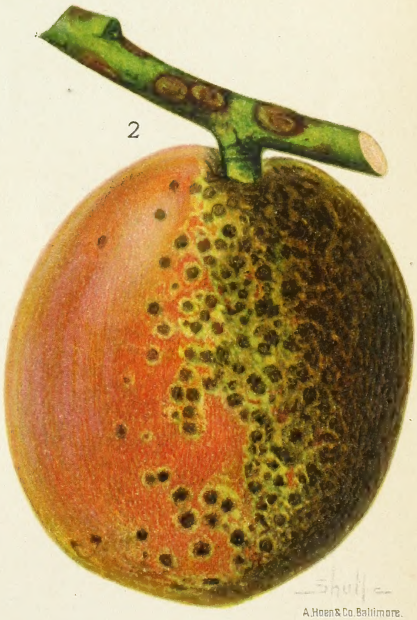

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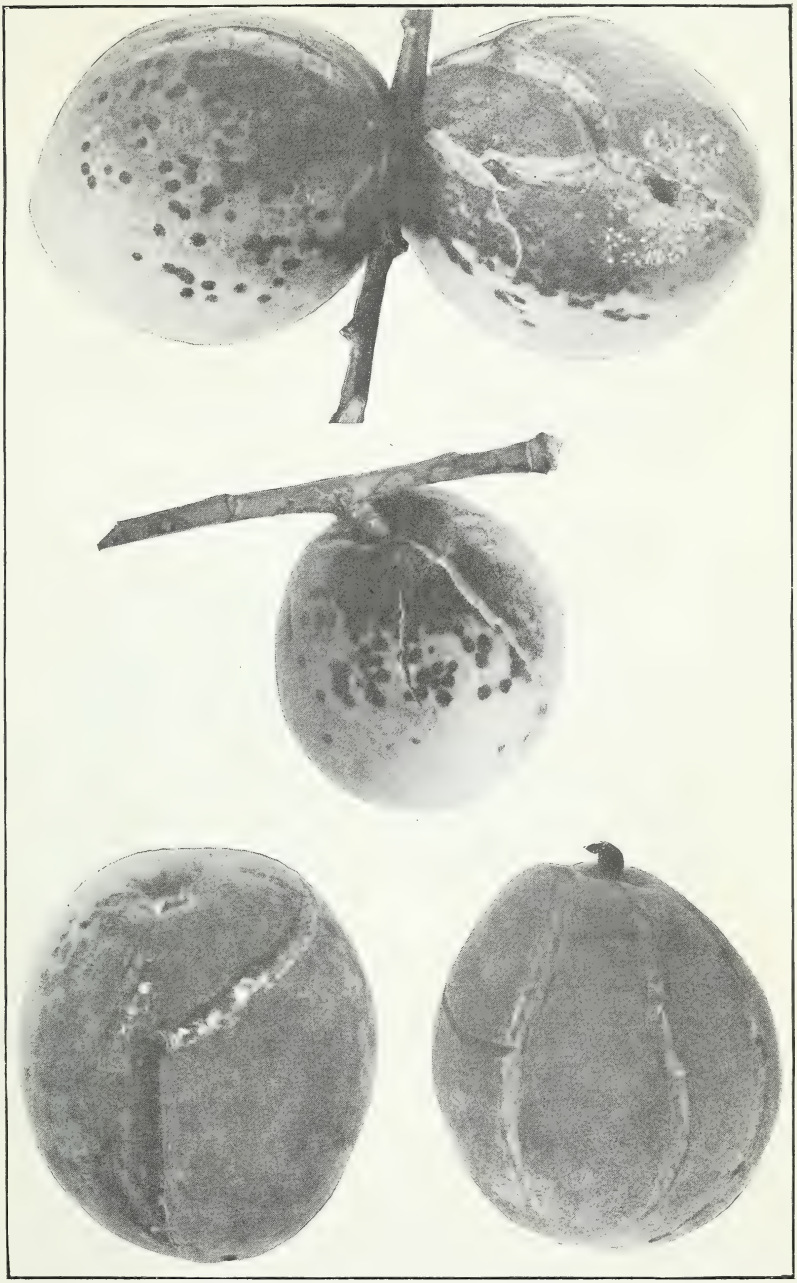
A. Hoen & Co. Baltimore.

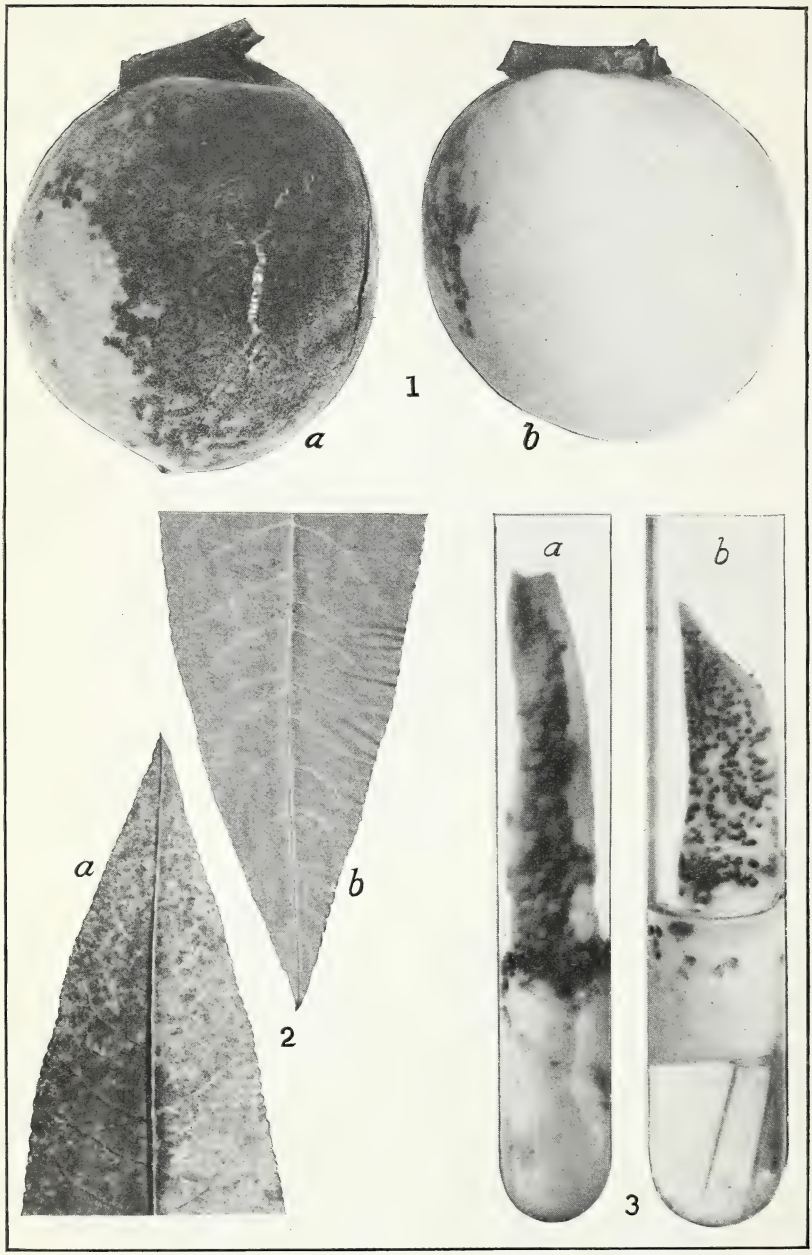
PEACH FRUITS, TWIGS, AND LEAF ATTACKED BY CLADOSPORIUM CARPOPHILUM.

FIGS. 1 and 2.—Badly diseased Elberta fruits from Chevy Chase, Md., August 6, 1915 (about a week before harvest). FIG. 1.—Cracking of the diseased area. FIG. 2.—Close proximity of twig lesions to the infected area of the fruit. FIGS. 3 and 4.—Early stages of infection on twigs of 1-year-old Early Crawford trees from inoculation experiments at Madison, Wis., August 6, 1915. Painted 40 days after inoculation. FIG. 5.—Typical natural infection on an Elberta twig from Chevy Chase, Md., September 16, 1915. FIG. 6.—Well-developed lesions on an Elberta twig in the spring following infection. FIG. 7.—Badly diseased leaf of a Heath tree from Chevy Chase, Md., September 16, 1915.



ELBERTA PEACHES BADLY ATTACKED BY CLADOSPORIUM CARPOPHILUM.

The upper figure shows brown-rot following scab. From Chevy Chase, Md., August 6, 1915, about a week before harvest. (Natural size.)



CLADOSPORIUM CARPOPHILUM ON PEACH FRUIT AND LEAF AND IN CULTURE.

FIG. 1.—Badly diseased Elberta fruit, showing typical distribution of infection: *a*, Surface most exposed to wetting, abundantly infected; *b*, surface least subject to wetting, no disease evident. From Chevy Chase, Md., August 6, 1915. (Natural size.) FIG. 2.—Distal portion of a badly diseased Heath leaf, showing typical distribution of the infection: *a*, Lower surface, abundantly infected; *b*, upper surface, no infection evident. From Chevy Chase, Md., October 5, 1915. (Nearly natural size.) FIG. 3.—Cultures: *a*, On steamed bean pod; *b*, on steamed potato cylinder. Photographed when cultures were 30 days old. (Natural size.)

TABLE I.—*Peaches and nectarines—trees, production, and value in the United States.*

Geographic division.	1910		1909		1899
	Trees of bearing age.	Trees not of bearing age.	Production.	Value.	Production.
	Number.	*Number.*	*Bushels.*	*Dollars.*	*Bushels.*
United States	94,506,657	42,266,243	35,470,276	28,781,078	15,432,603
Groups of States:					
New England	723,810	572,237	406,903	632,411	104,737
Middle Atlantic	6,056,690	5,759,925	3,201,493	4,018,034	1,231,242
Eastern North Central	11,035,119	6,972,375	5,120,841	5,172,957	716,670
Western North Central	13,265,526	2,582,028	1,643,257	1,250,944	212,932
South Atlantic	20,583,445	6,137,901	5,571,628	4,888,459	1,412,471
Eastern South Central	10,312,768	3,865,232	5,775,799	4,098,776	549,226
Western South Central	22,284,966	8,734,552	3,279,545	2,761,044	2,192,353
Mountain	1,605,285	1,696,111	940,168	1,071,446	267,365
Pacific	8,639,048	5,945,882	9,530,642	4,887,007	8,745,607

Though the nectarine is represented in these figures, it is relatively so unimportant that for purposes of rough estimation it may be left out of consideration. According to these estimates, in 1910 there were in the United States 94,506,657 bearing peach and nectarine trees, which, during the preceding year, yielded a crop valued at $28,781,078. The greater portion of the trees in the South Atlantic, eastern South Central, western South Central, eastern North Central, and Middle Atlantic States, estimated at 70,272,988, are in sections subject to serious losses from scab. Those of the New England and western North Central States, numbering 13,989,336, with the exception of those in the more southern areas, as Missouri (6,588,034) and Kansas (4,394,894), are generally distinctly less seriously affected, while the 10,244,333 trees of the Mountain and Pacific States, only 10.8 per cent of the total number, may be classified as free from economic injury by scab.

Inasmuch as any accurate computation of the losses occasioned yearly by the disease would of necessity be based upon such undeterminable factors as actual losses and expenditures for preventive treatments, a concrete estimate is scarcely profitable. The experience of the years immediately preceding the development of control measures, however, emphasizes the potential damage of the disease. During this period, owing to the combined ravages of brown-rot and scab, commercial peach growing in the southern portions of the United States suffered a severe check, while even in the eastern and central sections plantings of certain varieties had to be discontinued or confined to the higher altitudes in order to escape scab. With the improved standards of excellence which successful summer spraying has instituted and with the cumulative development of the disease in unsprayed orchards, it is evident that if no scab control were available the disease would be a serious menace to successful commercial peach culture in many sections of the southern, eastern, and central United States.

DESCRIPTION.

On fruit.—The earliest macroscopic evidences of infection upon the green surfaces of the fruit appear as imperfectly defined, greenish to olivaceous, circular areas, usually less than half a millimeter in diameter. This effect is due to the appearance of the olivaceous conidiophores and conidia of the fungus among the hairs of the fruit. Upon blush surfaces, the early development of olivaceous color may be accompanied or preceded by the disappearance of the normal pink from the invaded areas, which remain much paler than normal until masked by the development of the fungus. In such cases a narrow peripheral zone of pale or yellowish green may mark the advance of each diseased area. The developing lesions gradually become larger, darker, and more clearly defined, owing to the death and disappearance of many of the obscuring hairs of the fruit and to growth and pigmentation of the fungus. When fully developed they are fairly well defined, circular, olivaceous to black areas with an average diameter of 2 to 3 millimeters, though under very favorable conditions they may attain a diameter of 4 or 5 millimeters (Pl. I, figs. 1 and 2, and Pl. II). The direct injury is superficial, involving at most only a few layers of cells, which typically become separated from the adjacent normal tissues by the formation of cork. The infections occur practically exclusively upon the areas which are subject to thorough wetting. The lesions are, thus, generally most abundant about the peduncle and upon the upper portion of the wettable [1] surface (Pl. III, fig. 1, *a*). They may be more or less uniformly scattered over the entire wettable surface, or they may be so abundant as to become confluent over large patches, frequently covering practically one-half of the surface of the fruit. The protected surfaces of even the most severely attacked fruits are usually free from infection (Pl. III, fig. 1, *b*). As the peaches grow rapidly just prior to maturity, the corked areas can not expand so readily as the normal tissues. This condition may result in mere inequalities of development between badly diseased and normal areas, but more commonly the growth stresses occasion the cracking of the cork layers. These cracks may appear upon individual lesions as small rifts extending slightly into the flesh, but upon very badly affected specimens they may extend the length of the fruit and penetrate to the pit (Pl. I, fig. 1). Badly scabbed fruits do not ripen evenly and are frequently inferior in flavor. Those which are severely scabbed about the attachment of the peduncle may be shed prematurely.

[1] In the earlier stages of development of the peach, its hairy surface is very resistant to wetting. With growth and weathering, however, that portion which is exposed to the action of falling meteoric water becomes more easily wettable, while the area protected from such action, usually the opposite side of the fruit, remains difficultly wettable throughout the important period of scab infection. For the sake of convenience, these areas subsequently will be referred to as "wettable" and "protected," though it should be realized, of course, that these terms are relative, not absolute.

On twigs.—On tender young green twigs, the first macroscopic evidences of infection, typically, are barely visible, more or less imperfectly defined, very slightly raised, irregularly circular to oval areas, almost indistinguishable in color from the surrounding normal surfaces. As the lesions develop, their central areas become light brown, and later darker brown, and each is bordered by a slightly raised peripheral zone, usually about half a millimeter wide and of approximately the normal green color. The coloration and zonation, however, may vary considerably with such factors as the age and character of the twig, seasonal conditions, and the stage of development of the disease. At the end of the growing season, well-developed lesions appear as smooth, irregularly oval, light-brown to dark-brown areas of normal elevation, with slightly raised purplish to dark-brown borders, which usually vary from one-half to 1 millimeter in width and shade off peripherally into the color of the surrounding normal surface (Pl. I, figs. 3 to 5, and Pl. IV, fig. 2). Such lesions usually measure 3 to 5 by 5 to 8 millimeters, the greater development being parallel to the axes of the twigs. The injury is superficial, involving only a few layers of the cells, the diseased areas becoming separated from the adjacent normal tissues by the formation of cork layers. Under favorable conditions, conidiophores, which bear typical conidia, may be produced upon the surfaces of the infected areas at any time after the lesions become macroscopic. During the summer and fall following the infection, the conidiophores are ordinarily produced singly, and seldom in such quantity as to be macroscopically evident. In the following spring, however, they are produced abundantly in olivaceous tufts. These sporiferous tufts may develop over the entire surfaces of the lesions, or they may be confined to peripheral zones, usually 1 to 2 millimeters in width, leaving the grayish brown central areas bare (Pl. I, fig. 6, and Pl. IV, fig. 3). Such lesions may enlarge slightly during the spring and early summer of the second season. As the summer progresses and the bark is differentiated, however, they gradually begin to lose their identity. By the third summer, they usually become indistinguishable, while the fungus rarely survives the second winter. Lesions on water sprouts or very rapidly growing twigs may lose their identity with the rapid cork formation of the first summer. Twig infections are miscellaneously distributed upon the wood of the current year's growth. They may be sufficiently numerous to become confluent and form irregularly shaped lesions, which may attain a length of several centimeters. On account of their superficial nature, however, they rarely cause appreciable injury to the twigs.

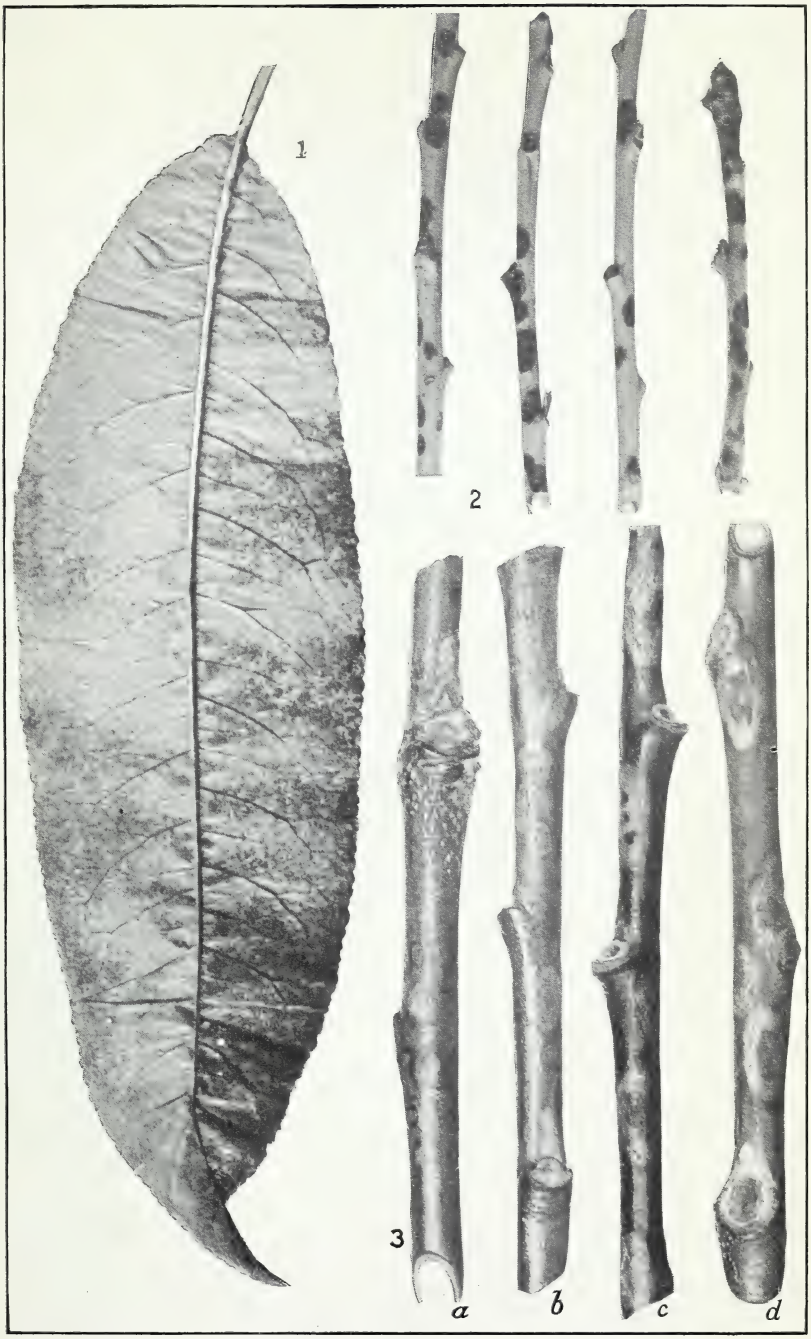
On leaves.—The first macroscopic evidences of infection appear upon the lower surfaces of the leaves as indistinct, imperfectly defined, somewhat angular to circular discolored areas, usually one-half to 1 milli-

meter in diameter. The color of the affected surface may be a pale green, almost indistinguishable from the normal, or it may vary to light brown or pinkish purple. The true color, however, is frequently modified or masked by an abundant development of olivaceous conidiophores and conidia. These are usually present in greater or less numbers when the infection first becomes macroscopic. When conditions especially favor their development, they may be borne in sufficient quantities to give a dark-green color to the lesions and to constitute their most conspicuous character. On the leaf lamina the fully developed lesions are somewhat angular to irregularly circular. Their average diameter is 1 to 2 millimeters, though in rare cases they may attain a diameter of 5 or 6 millimeters (Pl. I, fig. 7, and Pl. IV, fig. 1). On the petioles and midribs they are usually much longer and narrower, generally measuring 3 to 8 by one-half to 1 millimeters. The color of the blotch proper may vary from light brown to dark brown, or it may be pinkish purple. The demarcation remains indistinct and the elevation is usually unchanged, except in extreme cases, when the lamina above the larger lesions may become convex below and correspondingly concave above. When the lesions first appear, no evidence of disease is visible upon the upper surfaces of the leaves. In later stages, however, the tissues above and immediately around the affected areas may lose some or all of their green color and become pale yellow or purplish. In extreme cases such areas may die, but ordinarily no definite leaf spotting is induced. The lesions may occur miscellaneously scattered over the lower surfaces of the leaves and upon the petioles, or they may develop in such abundance as to become confluent and form irregular patches (Pl. III, fig. 2). The infection appears to occur with equal readiness on the petioles, midribs, veins, and leaf lamina. It was demonstrated in the inoculation experiments that badly diseased leaves may turn yellow and fall, but the writer has rarely observed this condition as the result of natural scab infection.

PATHOLOGICAL HISTOLOGY.

Histological technique.—In killing material for histological work, several standard fixing agents were employed, viz, Flemming's weak, medium, and strong fluids, picro-formal, and chrom-acetic. The stains used were Flemming's triple, Haidenhain's iron alum-haematoxylin, Durand's haematoxylin-eosin, gentian violet, and safranin.

For most purposes, Flemming's medium fluid and the triple stain gave the best results. This combination not only stained the fungus well, but gave an excellent differentiation of fungus and host in twig and fruit lesions. The cuticle of the host remained practically colorless, while the dead epidermal and subepidermal cells took little stain, being yellowish green in the finished preparation. In sharp



PEACH LEAF AND TWIGS ATTACKED BY CLADOSPORIUM CARPOPHILUM.

FIG. 1.—Lower surface of badly diseased Heath leaf, showing abundant infection. From Chevy Chase, Md., October 5, 1915. (Natural size.) FIG. 2.—Badly diseased Elberta twigs. From Chevy Chase, Md., August 6, 1915. (Natural size.) FIG. 3.—Elberta twigs, showing lesions as they appear in the spring following infection, with abundant production of conidial tufts: *a* and *b*, Small lesions, evidently the result of late infection; *c* and *d* fully developed lesions. From Cornelia, Ga., May 31, 1912. (Magnified, × 2.)

contrast, the fungal tissue took up the red and orange quite freely, while the dividing cells of the cork-forming layers stained a striking blue and the normal host cells below a bright red.

Fruit lesions.—In the early stages of fruit infection the slender, branching, hyaline, septate hyphæ of the fungus are found closely appressed to the inner walls of the irregular surface cells of the host. This early development is most abundant in the minute depressions about the bases of the hairs, where conditions seem to be particularly favorable for the development of the parasite (fig. 1). As the fungus becomes firmly established, conidiophores are produced, while the vegetative hyphæ branch and thicken until they may entirely cover the area of infection. The individual cells thicken and darken, while transverse and longitudinal divisions take place, often resulting in the formation of irregular fungal masses five or six cells in depth (fig. 2, *a*). This later development, too, is particularly abundant in the depressions about the bases of hairs.

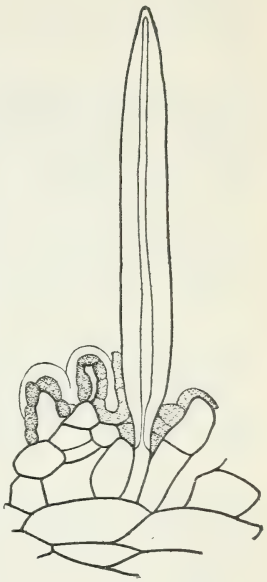


FIG. 1.—Section of a lesion from an Elberta peach fruit, showing the early development of the parasite about the base of a hair, in close contact with the inner walls of adjacent surface cells of the host. Camera-lucida drawing. (Magnified 465 times.)

As the fungus develops generally over the surface of the infected areas, the superficial host cells die and the lesions may be cut off from the sound tissues below by the formation of protective layers of cork (fig. 2, *b*). These layers are formed as the result of tangential divisions of the subepidermal cells. Less frequently, transverse divisions occur. Cork formation is usually most vigorous in the third or fourth subepidermal layers and ordinarily extends slightly above and below this actively dividing region.

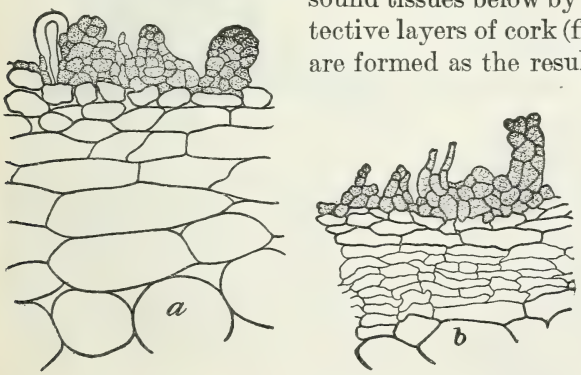


FIG. 2.—Sections of lesions from Elberta peach fruits: *a*, Shortly before cork formation; *b*, soon after cork formation. At the right the section extends nearly to the edge of the corky layer. Camera-lucida drawings. (Magnified 310 times.)

In the case of early varieties of peaches, the fruits usually mature before cork formation occurs. Upon later varieties, however, the

cork layers may be formed before the final rapid swelling of the fruit prior to its maturity. In such cases stresses are set up and cracks of varying sizes result. In many cases such openings are scarcely macroscopic, but on badly diseased fruits, where the spots have become confluent, the cracks may extend across an entire side of the peach and reach inward to the pit.

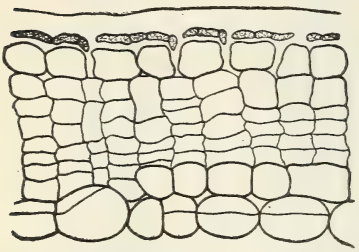


FIG. 3.—Longitudinal section of a lesion from an Elberta peach twig of the current year's growth, showing the early subcuticular development of the fungus and a very early stage of cork formation. Camera-lucida drawing. (Magnified 310 times.)

Twig lesions.—In the early stages of twig infection, slender, branching, hyaline, septate hyphæ of the fungus are found penetrating the subcuticular areas immediately exterior to the cellulose walls of the epidermal cells (fig. 3). As the fungus develops, its ramifications become more general, its individual cells thicken, the underlying epidermal cells of the twig die, and the diseased areas are effectively cut off from the sound cortical tissues below by layers of cork cells. These corky layers are formed by means of tangential divisions of the subepidermal cells. It is not unusual, however, for the first division to be transverse, the daughter cells dividing tangentially. The two or three actively concerned hypodermal layers are, in each case, rapidly converted into a fairly uniform barrier of thin corky cells of meager protoplasmic content. As the lesions age and the epidermal cells become more and more disorganized, the outer layers of subepidermal cells die and turn brown.

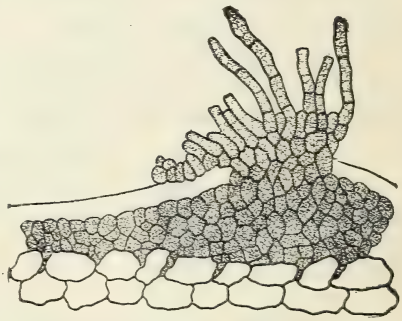


FIG. 4.—Longitudinal section of a lesion from an Elberta peach twig of the preceding year's growth, showing the abundant subcuticular development of the fungus and the vigorous production of conidiophores in the spring following infection. The host cells, which were badly disorganized, are semidiagrammatically represented. Camera-lucida drawing. (Magnified 310 times.)

After the advent of the dormant period of the host, the fungus continues to develop throughout the fall, mild periods of the winter, and the spring. The subcuticular hyphæ increase in diameter and in number until they form stromateoid layers which may extend over the entire lesions. While these structures may consist merely of single layers of cells, they are usually thicker, often developing into pseudoparenchymatous masses, six or eight cells deep (fig. 4).

With the vigorous subcuticular development of the fungus, the cuticle is often slightly raised and at times broken, while the remains

of the dead epidermal cells are compressed inward in extreme cases until their identity is almost lost. In such cases the fungus often grows down between the epidermal cells, and occasionally hyphæ penetrate the intercellular areas of the first subepidermal layer.

After the protective corky layers are fully formed, no further pathological anatomical changes occur. As the bark forms and roughens with the second year's growth of the twigs, the cuticle of the diseased areas partially sloughs off; and, as the bark thickens with subsequent development, the lesions gradually lose their identity.

Leaf lesions.—In the early stages of leaf infection, the slender hyphæ of the fungus are found between the cuticle and the cellulose walls of the epidermal cells of the lower (dorsal) surface. As the fungus develops, its ramifications become more abundant, and under favorable conditions conidiophores and conidia are produced. Its ultimate development, however, is much less vigorous than upon twigs or fruit, no pseudoparenchyma having been observed on the leaf lamina. The invasion appears to be merely subcuticular and the fungus is very inconspicuous, even in well-stained preparations. The chlorophyll usually disappears from the mesophyll cells immediately adjacent to the invaded areas, while in extreme cases this abnormality extends into the leaf lamina to such an extent that the areas above the lesions appear distinctly yellow or purplish when viewed from the upper (ventral) surface.

When infection occurs upon the petioles or larger veins, corky layers similar to those described for fruit and twig lesions are formed. In such cases the development of the fungus is distinctly more vigorous than on the leaf lamina, but much less so than on fruits and twigs.

THE CAUSAL ORGANISM.

TAXONOMY.

Von Thümen (1877), at Klosterneuberg, Austria, first described the peach-scab fungus, naming it *Cladosporium carpophilum*. Two years later the same author (1879, p. 13) emended his original description. Saccardo (1886, p. 353) gives Von Thümen's emended description in slightly abbreviated form. Arthur (1889, p. 7) reviews the references cited above and gives a translation of Von Thümen's emended description. Oudemans (1901, p. 388) describes as *Fusicladium carpophilum* Oud. a fungus growing on fallen young peaches. He lists as a synonym *Cladosporium carpophilum* Thüm., but neither gives Von Thümen credit as authority for the specific name nor states reasons for transferring the fungus to the genus Fusicladium. Aderhold (1900, p. 541–549; 1901, p. 656–657), after extensive investigations, concluded that *Fusicladium cerasi* (Rbh.) Sacc. should be referred to the genus Cladosporium. On comparing this

fungus with *Cladosporium carpophilum* Thüm. from peach fruit from America, he found only minor morphological differences, but obtained inconclusive results from cross-inoculation experiments. Though he does not formally conclude that these organisms are specifically identical, he expresses the personal conviction (1901, p. 657) that they are "ein und denselben Pilz" and calls attention to the fact that Pammel (1895, p. 207) and Selby (1897, p. 118) considered Cladosporiums associated with cherry and plum scab in America to be *Cladosporium carpophilum* Thüm. If Aderhold were correct in his belief, it would follow that *Cladosporium carpophilum* Thüm. should become a synonym of *Cladosporium cerasi* (Rbh.) Aderh., which in turn the same investigator (1900, p. 544) considers to be the imperfect stage of *Venturia cerasi* Aderh. The data which have been presented, however, fail to convince the writer that the organisms in question are identical. Therefore, until further evidence is adduced, he accepts the name *Cladosporium carpophilum* Thüm. for the peach-scab parasite.

While the contributions which have been made to the knowledge of *Cladosporium carpophilum* since Von Thümen's (1879) description make desirable certain further emendations, it is the belief of the writer that, in order to avoid unnecessary taxonomic complications, these should not be made until the relationships of the Cladosporiums on the stone fruits have been further determined. Meanwhile, Von Thümen's (1879, p. 13) description, which is quoted below, is in most essentials clear-cut and accurate.

Cl. maculas orbiculares, saepe confluentes, viridi-nigricantes, annulatas formans; hyphis brevibus, erectis, flexuosulis, continuis vel interdum septatis, subramosis, tenuibus, 4 mm. crassis, fuscis; sporis fusoideo-ovatis, utrinque obtusiusculis vel raro vertice subacutatis, rectis, non vel obscure uniseptatis, diaphanis, 20 mm. long., 5–6 mm. crass., dilute fuscescentibus.—Thümen. l. c. emend.

In *Persicae vulgaris* Mill. fructibus maturis, epidemice.—Austria inferior (Thümen).

MORPHOLOGY.

Mycelium.—The morphological characters of the mycelium vary much with conditions. The very young hyphæ are delicate, hyaline, branched, and septate. As the fungus develops, however, the diameter of individual cells normally increases, transverse and, more rarely, longitudinal divisions occur, and the walls of the more exposed cells thicken and become olivaceous. On the fruit lesions this growth may give rise to pseudoparenchymatous fungal masses, while a like development may occur beneath the cuticle of the twigs (figs. 2 and 4). In culture, stromateoid masses develop (Pl. III, fig. 3), the individual cells becoming much enlarged and often rounded, giving an irregularly moniliform appearance to the mycelial threads. In old cultures the mycelium tends to break up into its component cells, which under favorable conditions are capable of putting out vigorous hyphæ. In all of these stromateoid structures the walls of

the more exposed cells thicken and darken and the individual cells may assume the characters of chlamydospores (fig. 5, *d* and *e*). On old cultures on steamed peach twigs or certain agar preparations, small, irregularly rounded to distinctly elongated, olivaceous, sclerotioid masses, usually less than one-third of a millimeter in diameter, may be found. The outer cells of these bodies are thick walled and olivaceous and frequently bear conidiophores. The inner cells are thin walled and colorless, with an abundant content of oily material.

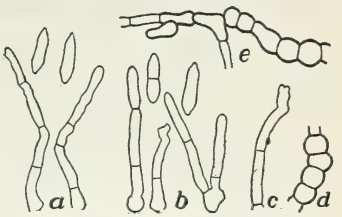


FIG. 5.—*Cladosporium carpophilum: a*, Conidiophores and conidia from fruit lesions; *b*, conidiophores and conidia from twig lesions; *c*, conidiophore from leaf lesion; *d*, and *e*, fragments of mycelium from Lima-bean agar culture, showing development of chlamydospores. Camera-lucida drawing. (Magnified 485 times.)

Conidiophores.—The conidiophores (fig. 5, *a*, *b*, and *c*) are short, erect, more or less flexuous, one to several septate, rarely branched, olivaceous hyphæ, distinctly enlarged at the base and often tapering irregularly toward the apex. Their dimensions vary with conditions, though in nature they are fairly uniform during the early stages of sporulation. The conidia are produced acrogenously, beginning usually when the sporophores are about 30 to 35 μ long. The conidiophores elongate apically as conidia are developed, the places of attachment of detached spores being marked ordinarily by small wartlike processes or by geniculations on the sporophores. The extent of this type of elongation, which is quite variable, determines the ultimate length of the conidiophores. On the overwintered twig lesions the conidiophores borne from the subcuticular stromateoid fungal masses occur typically in tufts (fig. 4), and tend to be somewhat shorter and thicker than those occurring elsewhere in nature. On the fruit they grow much longer, often attaining a length of 90 to 100 μ. On leaf infections and twig lesions of the current year they tend to be somewhat more erect and less flexuous than on fruit or overwintered twigs. In culture there is much greater variation, the sporophores ranging from undifferentiated hyphæ to abnormally long, slender filaments. Measurements of conidiophores are summarized in Table II.

TABLE II.—*Measurements of conidiophores of Cladosporium carpophilum.*

Source.	Number measured.	Average measurements (microns).		Source.	Number measured.	Average measurements (microns).	
		Length.	Breadth at middle.			Length.	Breadth at middle.
Fruit	10	63.5	4.6	Twig of current year [1]	10	48.5	4.7
Do	10	65.0	4.2	Leaf	10	57.9	4.6
Do	10	73.0	4.2	Do	10	60.8	4.6
Overwintered twig	20	42.1	5.5	Do	10	57.0	4.5
Do	10	42.7	5.0				

[1] Conidiophores in early stage of sporulation; consequently, relatively short.

Conidia.—The conidia (fig. 5, *a* and *b*) are borne acrogenously, either singly or in short chains which may be branched when conditions especially favor sporulation. The spores appear first as small, rounded, hyaline projections from the apices of the conidiophores. These bodies rapidly enlarge, assume the ellipsoidal shape of the immature spore, and become abjointed by septa from their sporophores. The mature conida are very well described by Von Thümen (1879, p. 13).

* * * sporis fusoideo-ovatis, utrinque obtusiusculis vel raro vertice subacutatis, rectis, non vel obscure uniseptatis, diaphanis, 20 mm. long., 5–6 mm. crass., dilute fuscescentibus.

If divided, the spores tend to be slightly constricted in the middle. The cells are very similar in size and shape, except that the basal ones tend to be slightly thicker and the apical less obtuse. In nature, normal mature conidia are fairly uniform in size. When they are produced in chains, the mature apical spores are indistinguishable in size and shape from the basal. The results of the measurements of 240 conidia from various sources are summarized in Table III. These measurements agree closely with those of Von Thümen (1879) except that the spores average 4.3 μ shorter.

TABLE III.—*Measurements of conidia of Cladosporium carpophilum.*

Source.	Number measured.	Average measurements (microns).		Source.	Number measured.	Average measurements (microns).	
		Length.	Breadth.			Length.	Breadth.
Fruit	10	16.7	5.0	Leaf lamina	20	16.6	4.9
Do	50	14.4	5.2	Do	20	16.2	4.7
Overwintered twig lesions	50	15.5	5.2	Do	20	15.6	4.8
Twig of current year	20	16.8	4.8	Do	20	16.5	5.1
Do	20	14.9	4.2	Leaf midribs	10	17.2	4.5
				Average of 240		15.7	4.9

PHYSIOLOGY.

The objects of the physiological studies were (1) to gain a clearer comprehension of the responses of the fungus to its environment under controlled conditions, in order better to understand its behavior in nature, and (2) to furnish a further basis for the identification of the organism by other investigators.

CULTURAL STUDIES.

By means of the poured-plate method the fungus was readily isolated from freshly produced conidia from fruit, twig, or leaf lesions. At first, considerable difficulty was encountered, because the scab fungus developed so slowly that it became overrun by saprophytes. It was possible, however, to minimize the contamination by

collecting the spores in a platinum loop of water touched to the ends of sporulating hyphæ. In cases where other measures were necessary, individual spores were isolated by a method which the writer (1915) has described elsewhere. By the use of this method all the cultures reported upon in this bulletin were isolated from single spores.

The organism was also isolated from leaf and twig lesions by sterilizing the surfaces with mercuric chlorid in the usual fashion and plating fragments in agar preparations. This method, however, was rendered unsatisfactory (1) by the superficial nature and slow growth of the fungus and (2) by the prevalence of a species of Dematium which agrees morphologically with the description of *Dematium pullulans* De By. This organism grows very rapidly in culture and forms myriads of spores, from which it is very difficult to isolate the slow-growing Cladosporium.

In connection with these isolations, observations were made to ascertain what organisms are commonly associated with scab lesions. Hundreds of plates were made from scrapings from scab infections on fruits, twigs, and leaves. The media most commonly used were agar in water, with prune decoction added, Lima-bean agar, and Thaxter's potato hard agar. *Cladosporium carpophilum* developed uniformly when the plates contained freshly produced normal spores, but it frequently failed to appear if the lesions had passed through adverse conditions, such as exposure to excessive heat or drought. The following organisms appeared frequently: *Dematium* sp., *Hormodendron* sp., and two undetermined imperfect fungi, hereafter designated for convenience as undetermined fungi *A* and *B*. While these four organisms appeared frequently and abundantly, only the Dematium developed constantly. All occurred superficially, and all were readily isolated from apparently normal surfaces of fruits, twigs, and leaves, as well as from scab lesions. The Dematium and the Hormodendron were especially abundant on dead tissues. While there was little reason to suspect that any of these superficial fungi bore a causal relationship in the production of scab, they were all isolated in single-spore cultures and tested for pathogenicity. The results, which were uniformly negative, are discussed later.

CULTURAL CHARACTERS.

Strains of the fungus isolated from (*a*) fruit, (*b*) twig, and (*c*) leaf lesions, respectively, were grown comparatively in triplicate cultures on 31 media. No marked differences occurred in the behavior of strains from the different organs of the host, the variations being no greater than those observed in strains isolated from the same organ. The fungus grew well on this wide range of media, and

showed only minor variations upon the different substrata. The more important features of this work are outlined as follows:

Lima-bean agar plates.—In diffuse light in the laboratory, at 18° to 25° C., the conidium puts out one or more colorless septate germ tubes, each of which in two days may attain a length of about eight to twelve times that of the spore. The cells of these hyphæ then thicken, develop numerous lateral branches, and become olivaceous. The younger hyphæ behave in like fashion. Thus small, compact colonies develop, their central areas being composed of dense, pseudoparenchymatous masses of heavy, often swollen and moniliform, thick-walled, olivaceous cells from which radiate numerous branched hyphæ. The colonies usually become macroscopic within three to five days and attain their full development within two to four weeks. When fully developed they may be irregularly spherical to lens shaped or irregular and more or less submerged, depending upon the position of the parent spore. The exposed portion of the stromateoid mass is masked by an olive-green covering of conidiophores, conidia, and rather sparse, slender, olivaceous, aerial hyphæ. The submerged parts are dense and black, except at the periphery, where the young hyphæ are colorless. While the size of the colonies varies much with conditions, the surface diameter averages about 1 to 4 mm.

Lima-bean agar slants.—The early development of the fungus parallels that on plates. The subsequent growth, however, is much more vigorous and continues for a longer period. In a culture seeded with a small droplet of sporiferous suspension on the middle of the slanted surface and incubated at 18° to 25° C. under conditions which retard rapid evaporation, the colony may eventually occupy practically the entire slant, gradual growth continuing for more than three months. At the end of four months the exposed portion consists of a black, irregularly circular, stromateoid mass about 1 to 1½ cm. in diameter, somewhat raised and slightly convoluted, masked by an olivaceous covering of conidiophores, conidia, and slender, aerial hyphæ. From this central mass heavy, branched, olivaceous to black hyphæ penetrate the slant practically to the wall of the tube.

Beerwort agar slants.—The early development closely parallels that on the Lima-bean agar, except that it is somewhat more rapid and the growth above the surface of the medium is markedly more abundant. The latter difference becomes very striking in later stages, when the much-folded and convoluted mycelial masses of the cultures on beerwort agar extend several millimeters above the original surfaces of the slants, sometimes reaching the opposite walls of the tubes. The subsurface development extends through the slants to the walls of the tubes. In the later stages the raised, stromateoid masses become studded with microsclerotia.

Other agar slants.—Strains of the fungus isolated from (*a*) fruit, (*b*) twig, and (*c*) leaf lesions were studied comparatively on 16 agar preparations, viz, infusions of peach fruit, peach leaf, peach twig, prune (pitted, 2 per cent and 5 per cent), Lima bean, potato, corn meal, oat meal, and string bean; standard beerwort, malt soup, synthetic, Thaxter's potato hard (3 per cent agar), beef-extract agar; and agar alone (1.5 per cent) in water. These media were prepared with the aim of securing as much uniformity as feasible in matters common to all, as periods of cooking and sterilization, percentage of agar used (1.5 per cent, unless otherwise noted), and technique of manipulations. For the standard media standard methods were followed throughout. All the media were titrated, but it was not considered desirable to readjust the reactions, previous tests having shown no noticeable effect of reaction in a range more extensive than that occurring in these cultures. The cultures were made in triplicate, incubated in darkness at 20° to 22° C., and examined frequently during their development.

While the development of the fungus varied considerably with the different media, these variations did not appear to be of a nature to justify detailed descriptions. The chief differences were (1) the amount of growth above the surface of the slant, (2) the

production of microsclerotia, and (3) the depth of growth below the surface of the medium. The most conspicuous development above the surface of the substratum occurred on beerwort and synthetic agars. A greater or less development of this type and the production of abundant microsclerotia occurred on all the sugary media used. Little of the elevated stromateoid growth occurred upon starchy media, nor were microsclerotia observed in such cultures. The subsurface development on the starchy media, however, was very vigorous. On agar in water the fungus developed slowly until the colonies were about 1½ cm. in diameter, though they were considerably less dense than on the more nutritive substrata, and their development above the surface of the slant was very limited. The variations in strains from different organs of the host were very minor, being no greater than have been observed in strains isolated from the same organ.

Prune gelatin slants.—The early development of the fungus parallels that on prune agar. The subsurface growth, however, soon becomes considerably more rapid on the gelatin cultures. While no marked liquefaction is apparent, there is some evidence of the softening of the medium immediately adjacent to the advancing hyphæ. It is quite possible that liquefaction occurs very gradually, the liquefied areas being occupied by the fungus as rapidly as the medium becomes softened. The fully developed colonies occupy the entire slanted sections and extend somewhat into the medium below.

Lima-bean agar shake cultures.—The fungus develops quite vigorously and typically upon the surface of the medium, and good growth occurs to a depth of 1 to 2 mm. At greater depths colonies develop at various points throughout the culture, but they grow very sparsely and barely become visible macroscopically.

Other media.—The same strains of the fungus used for the agar slant cultures were grown comparatively, at the same time and under like conditions, upon the following media: Prune decoction (2 per cent) in (1) tubes, (2) elder pith, (3) plaster-of-Paris blocks, and (4) filter paper; peach fruit and leaf decoctions in filter paper; steamed bean pods; sweet-clover stems; peach twigs; peach leaves; potato plugs; rice; corn meal; and sterile raw potato plugs. The developments were not sufficiently distinctive to justify detailed descriptions. In the prune decoction the fungus developed abundantly at the surface of the liquid and formed fairly vigorous colonies along the walls of the tubes to the bottom. Good growth occurred on all the other media, though the development on raw potato was quite sparse while the plugs were fresh. Later, the growth was very good. The most striking feature of these cultures was the conspicuous development of microsclerotia upon the peach twigs. The differences among the strains were no more marked than in the agar slant cultures.

RELATIONS OF MOISTURE.

The cultural studies reported above showed that the fungus may grow vigorously on or in a suitable nutrient solution or saturated substratum. If the substratum was gradually dried, however, the cell walls of the fungus thickened and became olivaceous, and chlamydospores were developed in great abundance. In this condition the organism was found to be highly resistant to desiccation. This was strikingly shown in the case of Lima-bean agar slant cultures, which were made on December 8, 1911, and kept in the laboratory, where they dried gradually and became very hard and brittle. On April 15, 1915, mycelial fragments from one of these cultures were plated. Good growth and sporulation resulted.

RELATIONS OF TEMPERATURE.

Several series of cultures were incubated in darkness at carefully controlled temperatures ranging from 2° to 40° C. The media used were Lima-bean and beerwort agars and steamed string-bean pods. At 2° C. the growth was very gradual, becoming barely macroscopic in about a month. At 4° and 6° C. the development was slightly more rapid, while at 9° and 12°, respectively, it was conspicuously accelerated. The rapidity of growth increased steadily up to 20° C., while at 24° a slight increase over 20° could be observed. At 27° C. the development closely paralleled that at 24°, being, perhaps, slightly less rapid. At 30° to 32° C. the fungus rarely became macroscopic, while no growth occurred at 35°. Cultures incubated for three weeks at 35° C. developed vigorously, however, when the temperature was decreased to 24°.

It appears, therefore, that the minimal temperature for growth of the fungus on favorable substrata is less than 2° C.; the optimal, between 20° and 27°—about 25°; and the maximal, about 32°.

RELATIONS OF LIGHT.

Numerous cultures on Lima-bean and beerwort agar slants and steamed string-bean pods were incubated comparatively side by side in strong diffuse light and in darkness, at temperatures ranging from 20° to 25° C. Excellent development resulted in all cases, the cultures of the two series being practically indistinguishable, except for the fact that sporulation was uniformly distinctly more abundant in the case of those grown in light. Good sporulation, however, occurred in the cultures grown in darkness.

In certain cases, in January and February, parallel cultures were incubated for several weeks in a south window, where they were exposed to direct sunlight for several hours of each clear day. Inasmuch as no effort was made to segregate the effects of light and temperature, these experiments merely showed that cultures which had been frequently exposed to direct sunlight under these conditions appeared to suffer no permanent injury, their ultimate development being good.

It appears, therefore, that strong diffuse light exerts no marked influence on the vegetative development of the fungus, but distinctly favors sporulation.

Spore-Germination Studies.

More than a thousand germination tests were made with conidia from various sources under varied conditions. Only certain general aspects of the results will be considered here. Data regarding viability are given in another connection (p. 35).

The spores were placed in drops of sterile distilled water, meteoric water, and nutritive solutions, respectively, on glass slides in moist chambers; in liquid and solid media in Van Tieghem cells; and in plate cultures of agar infusions. The cultures were incubated under various regulated conditions. The glassware was cleaned in the standard manner for physiological experiments, and distilled water was redistilled from Jena glass. For most purposes, the open drop cultures on glass slides in Petri dishes were most convenient and satisfactory.

GERMINATION IN WATER.

In diffuse light or in darkness, at 18° to 27° C., the first evidences of the germination of conidia in sterile distilled water appear, after about 8 to 12 hours, as small, highly refractive, hyaline protuberances of the inner walls of the spores. These gradually develop into delicate, hyaline, septate germ tubes, 2 to 4 μ in diameter, which usually attain a length of about 10 to 20 μ within 24 hours after the beginning of the experiment. Little growth occurs after the second day, when the tubes are usually 30 to 60 μ long. They rarely become longer than 75 μ unless suitable nutritive material is added. The germ tubes may extend from any part of the surface of the spore, but ordinarily they are developed at or near the ends. If only one is produced, it is generally borne at or near the basal end. Frequently a tube is developed from each end, but rarely are more than two produced from a single spore in pure water.

In parallel experiments with sterile distilled water and meteoric water no noteworthy differences in results were observed.

GERMINATION IN NUTRIENT MEDIA.

In drops of 1 per cent prune or raisin decoction, or a variety of other similar nutrient solutions, the early development of germination is practically indistinguishable from that in water, the effects of the nutrient media being manifested chiefly in the rapidity and vigor of development. In such solutions, under the conditions already mentioned, early stages of germination may be observed within 4 to 8 hours. After 12 hours the germ tubes usually measure about 3 to 4 by 15 to 25 μ. Within two days they frequently attain a length of 150 to 250 μ and become considerably thickened, branched, and septate.

In sap expressed from green Elberta peaches germination is practically indistinguishable from that in 1 per cent prune decoction.

In plates of 1 per cent prune agar, or a variety of similar agar infusions, germination closely parallels that in drops of prune decoction.

In Van Tieghem cells the spores germinate normally in various liquid and solid media.

RELATIONS OF MOISTURE.

While no attempt was made to determine whether or not the conidia will germinate in a highly humid atmosphere in the absence of water, no evidence of this type of development was observed. On the contrary, cumulative observational data strongly indicate that at least a film of water is essential to germination. Continuous wetting, however, is unnecessary, as was shown in the following experiment:

Experiment 1.—Spores were placed in drops of sterile distilled water and 1 per cent prune decoction, respectively, on slides in moist chambers and incubated in diffuse light in the laboratory at 15° to 25° C. In one series the drops were not allowed to evaporate. In two others the spores were kept alternately wet and air dry for 24-hour periods, one series being wet during the first period and the other dry. The experiment was continued for six days and noted daily. The spores which were kept continuously moist germinated normally and at the end of the experiment showed somewhat better growth than the others. Those which were alternately wet and dry showed little if any injury from the treatment. They ceased to develop when dry, and resumed their activities when wet. At the end of the experiment these two series were indistinguishable in their development. Other similar tests in which the periods of wetting and drying were varied gave confirmatory results, no serious injury being observed unless the changes were very frequent in the earlier stages of germination.

RELATIONS OF TEMPERATURE.

Several series of germination experiments were conducted in drops of sterile distilled water and 1 per cent prune decoction, comparatively, on glass slides in moist chambers in darkness at carefully controlled temperatures ranging from 2° to 35° C. The spores were taken from vigorous Lima-bean agar cultures 2 to 4 weeks old. At 2° C. germination in sterile distilled water was practically nil, only occasional tubes, with a maximal length of about 20 μ, being observed at the end of 15 days. In the parallel cultures in prune decoction, early evidences of germination were visible after three days. Within four days numerous tubes 5 to 10 μ long were evident, while at the end of 15 days most of the spores had germinated, their tubes averaging more than 100 μ in length. At 4° and 6° C., respectively, the rate of development was slightly increased. At 9° and 12° C. it was in each case materially accelerated, and up to 20° it increased steadily. The cultures at 24° C. were slightly more advanced than at 20° and almost indistinguishable from those at 27°, though apparently very slightly more vigorous. At 30° to 32° C. the spores germinated but sparsely. The tubes in the prune decoction rarely exceeded 60 μ in length and failed to develop into mycelia or to produce spores. At 35° C. no germination was observed.

It appears, therefore, that the thermal relations of germination closely parallel those of subsequent growth, the minimal temperature for germination in water or in favorable nutritive solutions

being less than 2° C.; the optimal, between 20° and 27°—about 25°; and the maximal, slightly above 32°.

RELATIONS OF LIGHT.

Numerous drop cultures of the type just mentioned were incubated comparatively in strong diffuse light and in darkness at temperatures ranging from 20° to 25° C. Normal development resulted in all cases, the differences in illumination appearing to have no marked influence on germination.

PATHOGENICITY.

Relative to an inoculation experiment with *Cladosporium carpophilum* from culture, Chester (1897, p. 63) makes the following statement:

> Sown on the uninjured surface of green peaches, a slight growth resulted, in only a few cases simulating the natural infection; it was evident, however, that the peaches were at that stage of their development not in condition for the best development of the fungus on their surface. When the inoculation of the peach was accompanied by a puncture, the fungus developed and produced spots like those seen in nature.

Thus, no definite data are given concerning the source of inoculation, the method of experiment, or the results obtained, and no mention is made of controls. Furthermore, the writer's experiments, reported below, show that punctures are not essential to abundant infection, and that the utmost care is necessary for the attainment of reliable results from fruit inoculation with *Cladosporium carpophilum* in sections where scab occurs abundantly. This experiment, therefore, does not justify conclusions.

Aderhold (1901, p. 657) conducted a cross-inoculation experiment with *Cladosporium cerasi* and *C. carpophilum*. The results, however, were admittedly inconclusive.

The writer (1914a, 1914b) reported, in a preliminary way, positive results from inoculating peach fruits, twigs, and leaves with *Cladosporium carpophilum* from various sources. The results of these and further experiments are given more completely below. They comprise, so far as the writer has been able to ascertain, the only authentic records of positive results from inoculation experiments with this fungus.

Fruit Inoculations.

Preliminary experiments and observations of two seasons showed clearly that under field conditions where the disease occurs abundantly, successful fruit inoculations with peach scab must be planned to overcome the following difficulties: (1) The abundance of natural infection, rendered especially baffling by the long period of incubation of the fungus, and (2) the difficulty of obtaining at will condi-

tions suitable for infection. These conditions led to the development of a special technique, of which the following is a brief outline:

In order to overcome the first of these difficulties the fruits used for the inoculations were bagged as soon as practicable after the shedding of the calyces, and were kept protected in this manner throughout the course of the experiments; the number of controls was made as large as circumstances permitted; and the inoculations were made in numerous corroborative series upon areas least subject to natural infection, about one-half of the total number being made upon the protected equatorial surfaces, which are normally free from natural infection, even under the most severe conditions (Pl. III, fig. 1).

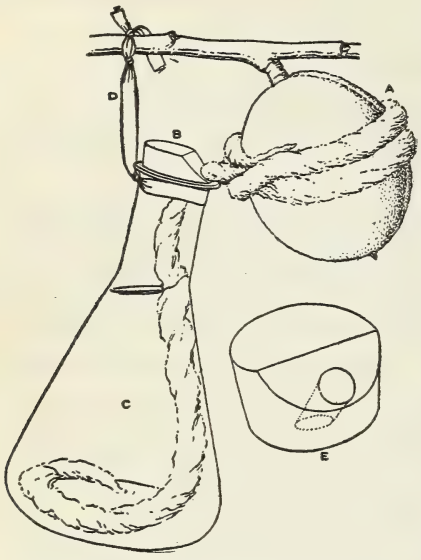


FIG. 6.—Device for supplying moisture for outdoor inoculations: *A*, Wick of absorbent cotton; *B*, cork; *C*, water container; *D*, attachment to host; *E*, enlargement of *B*. (*A* to *D* are about one-half natural size.)

The bags used were made to order from a thin, translucent, partially waterproofed (glassine) paper. They were 11 inches wide and 14 inches long, but 12 by 16 inches proved later to be a more convenient size.

In order to secure at will favorable conditions for infection it became necessary to devise a method for the satisfactory regulation of moisture. In continuation of preliminary experiments made in 1912 a very simple and satisfactory contrivance was developed. It was even better adapted to twig than to fruit inoculations and should be capable of general adaptation in inoculation work of this type, where moisture is a limiting factor and where it is impracticable to conduct the experiments in moist compartments. The apparatus, which works by capillarity, is readily understood by reference to figure 6. One end of a wick of wet absorbent cotton (*A*) is appressed to the area to be moistened, while the other end extends through a small orifice in a cork (*B*) into a water container (*C*), which is attached by means of a soft tape (*D*) to some convenient part of the host. The size and shape of the container may be adapted to suit the convenience of the operator. Lipped test tubes, 18 by 150 mm., were used in the earlier experiments, because they were the only suitable apparatus available at the time. They were quite satisfactory, but small, light, lipped flasks later proved more desirable, as they are more capacious and render the device more compact.

With the apparatus used it was found practicable to keep twig inoculations thoroughly moistened for two weeks without refilling, while a moist zone three-fourths of an inch wide could be maintained about a peach 1½ inches in diameter for four days. The container is refilled easily by removing the cork, without disturbing the arrangement of the upper portion of the wick. For convenience of attachment it is distinctly advantageous to allow the wick to enter the container from one side of the cork rather than from the center, while corks cut as shown in figure 6 (*E*) are easily manipulated and are unlikely to abrade the adjacent tissues of the fruit. If the wick fits loosely in the orifice or if the cork is lightly inserted in the flask, no strain is exerted upon the fruit by the swaying of the water container by the wind. Any such lateral motion is readily taken up by the short section of the wick which extends

from the mouth of the flask to the surface of the fruit. In many cases fruits can be found so situated that the neck of the flask may be firmly attached to the twig and swaying rendered impossible.

METHOD OF INOCULATION.

The method employed in the fruit-inoculation experiments of 1913, in all essentials applicable to all the fruit-inoculation work, is briefly described as follows:

All inoculation work of the season of 1913 was conducted in the orchard of Mr. I. C. Wade, Cornelia, Ga. The trees used were 8-year-old Elbertas, located on a sandy clay soil, with good air and surface drainage and a western exposure. On account of the freeze of March 29 the crop was very short. This part of the orchard was, consequently, unsprayed.

The experimental fruits were carefully selected and bagged on May 8, about three weeks after the falling of the calyces. The bags were of heavy manila paper, but they were replaced after a few days by the glassine bags, which had been delayed in shipment. The bagging was planned for an earlier date, but was delayed, pending the arrival of the glassine bags, as long as outdoor conditions seemed to render protection from natural infection unnecessary. The three weeks preceding May 8 were unusually favorable in this respect, comprising a period of unbroken drought except for a very slight shower on April 26 and another on April 27, both of which were followed by brisk winds which rapidly dried the trees. Furthermore, microscopic examinations of scab lesions on twigs from the field showed practically no production of conidia during this period. Thus any considerable natural infection of the experimental fruits prior to bagging was not considered feasible. The correctness of this assumption was clearly demonstrated in the course of the experiments, as will be set forth later.

The inoculations were made on noted oval areas about 3 cm. horizontally by 2 cm. vertically on the exposed and on the protected equatorial surfaces of the fruits. The spores were applied in suspension in sterile water or in nutrient solutions by means of sterile De Vilbiss atomizers. The surfaces inoculated, being highly resistant to wetting, were gently tapped with a finger, in order to facilitate the penetration of the spore-bearing liquid through the thatch of hairs to the epidermal cells. The hands were washed and rinsed in sterile distilled water prior to the application of each sporiferous suspension, and due precautions were, of course, observed throughout the operations to prevent mixing the sources of inoculation. As soon as each inoculation was made, a moisture apparatus of the type previously described was attached in such fashion as to maintain a moist zone approximately 2 cm. wide about the equatorial region of the peach. The bag was then replaced.

All apparatus used was thoroughly clean, and all glassware and metal ware was sterilized.

The watering apparatus, which functioned for about four days after filling, was refilled at noted intervals, which varied with the different series.

Throughout the season the inoculations were noted at intervals of about one week.

In certain cases bags were torn. The facts were noted and new bags were put on. There was no evidence of the entrance of infection in any such case. In the light of life-history studies outlined later, this is not surprising, since the rents always occurred in such position that an unbroken thatch covered the fruit and prevented access of water-borne spores.

All inoculations were made in triplicate unless otherwise noted, and germination tests were made with drops of each sporiferous suspension used.

REPORT OF A TYPICAL EXPERIMENT.

As illustrative of the fruit-inoculation experiments, one typical series planned for securing final evidence regarding the pathogenicity

to peach fruits of the organisms concerned is reported in some detail, as follows:

Sources of inoculation.—The sources of inoculation were 11-day-old Lima-bean agar cultures of single-spore strains of *Cladosporium carpophilum*, undetermined fungus *A*, undetermined fungus *B*, and *Dematium* sp., all of which had been isolated from peach twigs. Sporiferous suspensions were obtained by introducing a few cubic centimeters of sterile distilled water into each culture tube, scraping the surface of the fungal growth lightly with a sterile platinum needle, and shaking.

Germination tests were made on sterile glass slides in moist chambers with drops of the sporiferous suspensions used for the inoculations. The results are shown in Table IV.

TABLE IV.—*Summary of a germination test of the spores used in a typical fruit-inoculation experiment, Cornelia, Ga., 1913.*

Organism.	Estimated germination in 3 days (per cent).	
	Sterile distilled water.	Prune decoction.
Cladosporium carpophilum	80	99
Undetermined fungus *A*	99	99
Undetermined fungus *B*	90	90
Dematium sp. (budding)	99	99

Methods.—On June 6, fruits bagged on May 8 were inoculated, the technique above described being followed in every respect except that in one-half of the series 0.09 per cent prune decoction was substituted for distilled water in the sporiferous suspensions and in the moisture apparatus. The moisture devices were refilled with sterile distilled water on June 11, June 20, July 17, and July 23.

Results.—The detailed results of these inoculations are summarized in Table V.

On the 16 control areas, Nos. 421 to 424 and 437 to 440, not a single infection occurred. The results of Nos. 425 to 427, inoculated with *Cladosporium carpophilum*, are particularly striking and confirm beyond question those of preceding parallel experiments. On the six inoculated areas 406 infections developed, while on the uninoculated areas of the three fruits only one infection occurred. The results from the six similar inoculations, Nos. 441 to 443, in which prune decoction was substituted for distilled water, furnish still further confirmation of those of the preceding experiments, 127 infections occurring upon the areas inoculated. Only in the case of No. 441 did any infection appear upon uninoculated surfaces of these fruits, 12 lesions developing within a few millimeters of the peduncle. This case stands alone among the fruits bagged on May 8 and apparently represents an unusual instance of early infection about the peduncle prior to bagging. This infection, however, should not be allowed to lessen confidence in the results of the inoculation. That the infections upon the inoculated areas resulted from the inoculation and not from natural infection is conclusive, because (1) on 100 control areas in this and the three other series of similar experiments not one infection occurred; (2) the disease appeared upon the inoculated areas at the same time that it became evident upon each of the other similarly inoculated areas of this series; (3) the lesions about the peduncle were separated from those upon the areas of inoculation by a zone of clean surface three-fourths of an inch wide; and (4) in no case has natural infection been observed to occur abundantly about the stem cavity, over the equatorial wettable surface, and over the equatorial protected surface

of one fruit, even under the most severe conditions of natural infection (Pl. III, fig. 1). Nos. 428 to 436 and 444 to 452, inoculated with *Dematium* sp. and with the undetermined fungi *A* and *B*, developing no disease upon the areas of inoculation, confirm the negative results of preceding parallel experiments and may be considered as supplementary controls.

In this series, including 32 fruits, 15 scattered infections, which have not been discussed, occurred upon uninoculated areas. These evidently resulted from occasional chance infections, which obviously can not be entirely precluded in work of this type. Their number, however, is so small in comparison with the number of infections resulting from inoculations that they are clearly negligible. Furthermore, the areas of inoculation were so chosen with reference to the parts of the fruit subject to natural infection that even this minimal amount of chance infection appears to have been escaped, as is witnessed by the freedom from disease of all the 100 control areas.

TABLE V.—*Summarized results from a typical fruit-inoculation experiment, Cornelia, Ga., 1913.*

Inoculation.		Number of infections after stated number of days (28, 42, 52, or 60) had elapsed.																													
		On inoculated areas.								On uninoculated areas.												Total infections.									
										Wettable surface.																					
Source and medium.	Serial No.	Wettable surface.				Protected surface.				Above inoculated area.				Below inoculated area.				Protected surface.				On inoculated areas.				On uninoculated areas.			
		28	42	52	60	28	42	52	60	28	42	52	60	28	42	52	60	28	42	52	60	28	42	52	60	28	42	52	60		
Distilled water:																															
Control	421	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
Do	422	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	1	2		
Do	423	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Do	424	0	0	0	..	0	0	0	...	0	0	0	..	0	0	1	..	0	0	0	..	0	0	0	...	0	0	1	...		
C. carpophilum	425	0	5	45	63	0	0	55	128	0	0	0	0	0	0	0	0	0	0	0	0	0	5	10	191	0	0	0	0		
Do	426	0	6	41	48	0	6	24	35	0	0	0	0	0	0	0	0	0	0	0	0	0	12	65	83	0	0	0	0		
Do	427	0	8	42	66	0	10	61	70	0	0	0	1	0	0	0	0	0	0	0	0	0	18	103	136	0	0	0	1		
Undetermined fungus *A*	428	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	*a*1		
Do	429	0	0	0	..	0	0	0	...	0	0	0	..	0	0	0	..	0	0	0	..	0	0	0	...	0	0	0	(*b*)		
Do	430	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*a*0		
Dematium sp	431	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*a*0		
Do	432	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*a*0		
Do	433	0	0	0	..	0	0	0	...	0	0	3	..	0	0	0	..	0	0	0	..	0	0	0	...	0	0	3	(*b*)		
Undetermined fungus *B*	434	0	0	0	..	0	0	0	...	0	0	1	..	0	0	0	..	0	0	0	..	0	0	0	...	0	0	1	(*b*)		
Do	435	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*a*0		
Do	436	0	0	0	..	0	0	0	...	0	0	0	..	0	0	1	..	0	0	0	..	0	0	0	...	0	0	1	(*b*)		
Prune decoction (0.09 per cent):																															
Control	437	0	0	0	..	0	0	0	...	0	0	0	..	0	0	0	..	0	0	0	..	0	0	0	...	0	0	0	...		
Do	438	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Do	439	0	0	0	..	0	0	0	...	0	0	1	..	0	0	0	..	0	0	0	..	0	0	0	...	0	0	1	...		
Do	440	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1		
C. carpophilum	441	0	0	20	23	0	0	25	35	0	0	0	12	0	0	0	0	0	0	0	0	0	0	45	58	0	0	0	c12		
Do	442	0	0	4	4	0	0	10	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	19	0	0	0	0		
Do	443	0	0	8	8	0	0	24	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	50	0	0	0	0		
Undetermined fungus *A*	444	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	(*d*)		
Do	445	0	0	0	..	0	0	0	...	0	0	1	..	0	0	0	..	0	0	0	..	0	0	0	...	0	0	1	(*b*)		
Do	446	0	0	0	..	0	0	0	...	0	0	0	..	0	0	0	..	0	0	0	..	0	0	0	...	0	0	0	(*b*)		
Dematium sp	447	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*a*0		
Do	448	0	0	0	..	0	0	0	...	0	0	0	..	0	0	2	..	0	0	0	..	0	0	0	...	0	0	2	(*b*)		
Do	449	0	0	0	..	0	0	0	...	0	0	0	..	0	0	0	..	0	0	0	..	0	0	0	...	0	0	0	(*b*)		
Undetermined fungus *B*	450	0	0	..	..	0	0	..	...	0	0	..	..	0	0	..	..	0	0	..	..	0	0	..	...	0	0	..	(*d*)		
Do	451	0	0	..	..	0	0	..	...	0	0	..	..	0	0	..	..	0	0	..	..	0	0	..	...	0	0	..	(*d*)		
Do	452	0	0	0	..	0	0	0	...	0	0	0	..	0	0	0	..	0	0	0	..	0	0	0	...	0	0	0	(*b*)		

a Considered as supplementary controls.
b Considered as supplementary controls; no records were made for these fruits on these days.
c See discussion of results on p. 24.
d Fruit shed before results were conclusive.

SUMMARIZED REPORT OF ELBERTA INOCULATIONS.

A brief summarized report of the Elberta fruit inoculations is given below (Pl. V, figs. 1 to 5).

Sources of inoculation.—*Cladosporium carpophilum* from cultures and directly from abundantly sporulating lesions on peach twigs, and undetermined fungus *A*, undetermined fungus *B*, and *Dematium* sp. from cultures. Only young, vigorously sporulating Lima-bean agar slant cultures of single-spore strains isolated from peach twigs were used.

Methods.—Fruits bagged on May 8 were inoculated by the methods previously described in four series on May 16, May 20, May 27, and June 6, respectively, and the inoculated areas kept intermittently moist until maturity.

Results.—In a few cases the experimental fruits were shed or were lost by accidental mechanical injury, while in a few of the earlier direct inoculations the spores used failed to germinate. These inoculations are not included in this summary.

On 16 areas inoculated with undetermined fungus *A*, 16 with undetermined fungus *B*, and 16 with *Dematium* sp. no infection resulted. Consequently, these inoculations may be considered as supplementary controls.

On the 100 control areas of the four series, including as controls the 48 inoculations with the superficial fungi mentioned in the preceding paragraph, not one scab infection developed. Upon the entire protected surfaces of the 50 fruits in question only one lesion appeared, this being in all probability the result of a chance infection subsequent to the time of inoculation. Upon these 50 fruits the total number of infections was only 21, while 35 matured without showing any evidence of the disease.

On the 18 areas inoculated with *Cladosporium carpophilum* from pure cultures, 707 typical infections appeared, an average of 39 lesions on each inoculated area. Only one of the 18 inoculations failed to result in definite and satisfactory infection, this being undoubtedly due to some local imperfection in the conditions of the experiment. In only two cases did the disease develop on uninoculated areas, sparse infection occurring in both instances near the peduncles, well away from the inoculated surfaces.

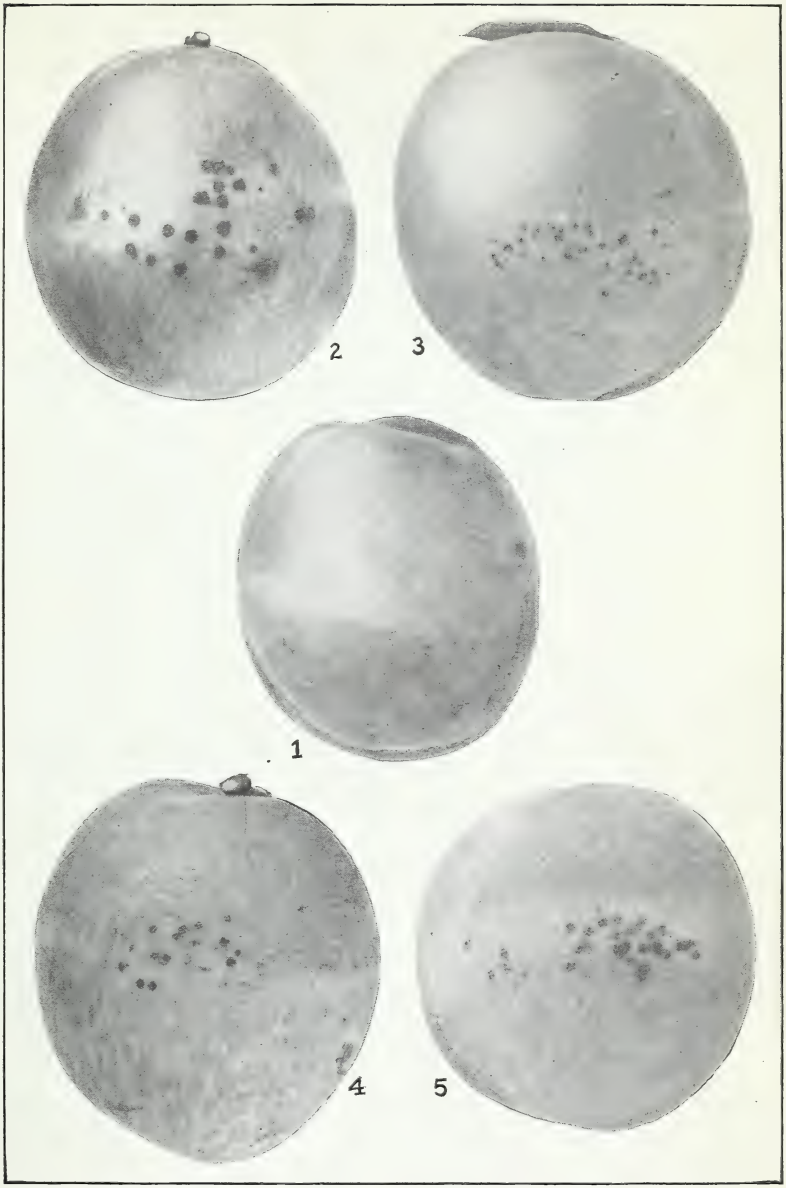
On the six areas directly inoculated with *Cladosporium carpophilum* from twig lesions, 63 typical lesions developed, every inoculation producing decisive infection. Only one lesion appeared upon the uninoculated areas of the four peaches in question. As these inoculations were made in two corroborative series and as four of them were situated upon the protected equatorial surfaces of the fruits, they were doubly guarded against natural infection and thoroughly justify positive conclusions.

CONFIRMATORY EXPERIMENTS OF 1914.

Experiments conducted at Madison, Wis., in 1914 were planned (1) to confirm the results of the preceding season in a locality where peach scab has not been observed to occur naturally and (2) to determine whether infection may occur during the early stages of development of the fruit. The report of these experiments is summarized as follows:

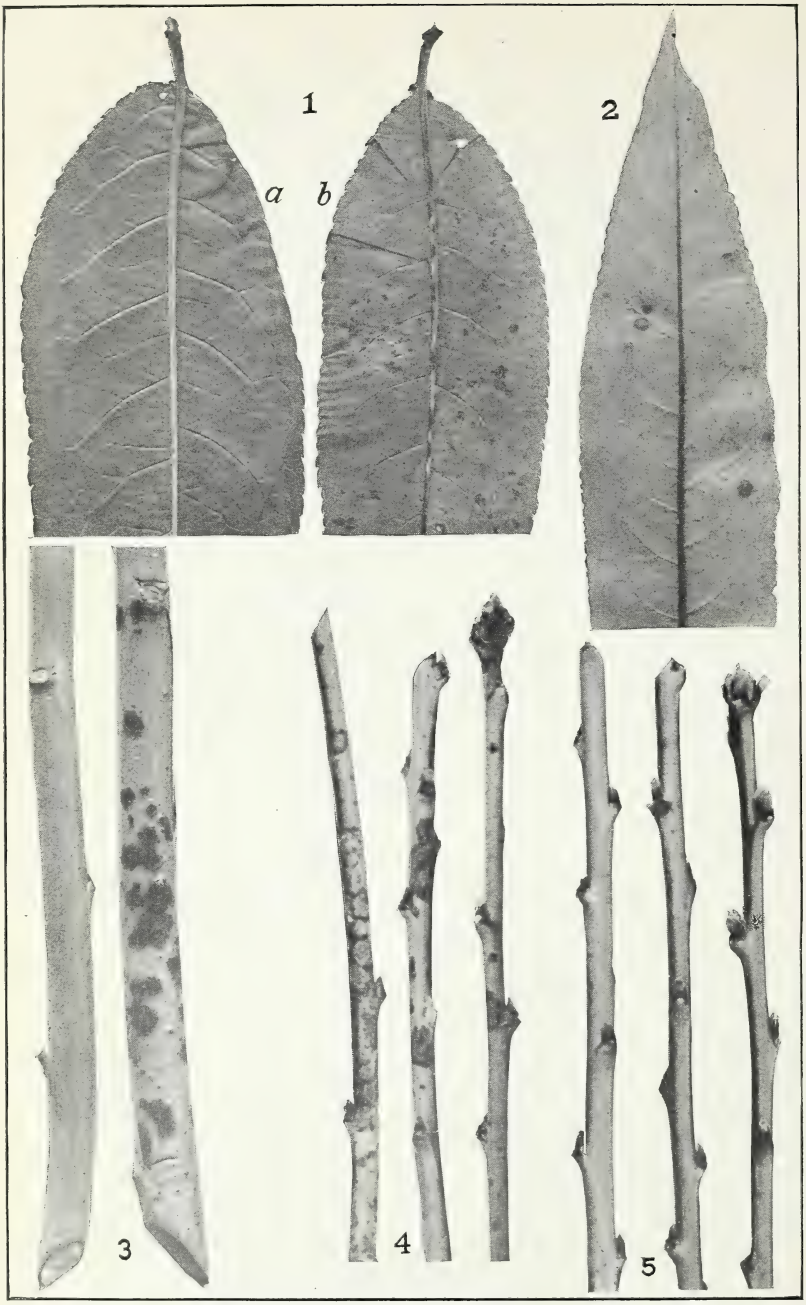
Sources of inoculation.—Abundantly sporulating young Lima-bean agar cultures of single-spore strains of *Cladosporium carpophilum* isolated from scab lesions of (*a*) fruit, (*b*) twig, and (*c*) leaf of the peach.

Methods.—On May 29, about a week after the shedding of the calyces, young Carman fruits about 8 mm. in diameter were inoculated, the methods of the Elberta inoculations of the preceding season being used throughout. The areas of inoculation and control were kept intermittently moist until June 23, when the bags and the moisture apparatus were removed and the fruits left free. Four fruits were inoculated from



ELBERTA PEACHES FROM INOCULATION EXPERIMENTS WITH CLADOSPORIUM CARPOPHILUM, CORNELIA, GA., 1913.

FIG. 1.—Control, no infection. Photographed August 4, 76 days after the beginning of the experiment. (Reduced, × 4/5.) FIGS. 2, 3, 4, and 5.—Inoculated with sporiferous suspensions from twig strains on noted areas of equatorial surfaces: 2, Inoculated May 20 and photographed 76 days later; 3 and 4, inoculated June 6 and photographed 59 days later; 5, inoculated May 27 and photographed 69 days later. All abundantly infected on inoculated areas. Photographed August 4. (Reduced, × 4/5.)



PEACH LEAVES AND TWIGS FROM INOCULATION EXPERIMENTS WITH CLADOSPORIUM CARPOPHILUM, MADISON, WIS., 1914.

FIG. 1.—Lower surfaces of Chili leaves: *a*, Control, no infection; *b*, inoculated by spraying with sporiferous suspension from fruit strain, badly diseased. Photographed 51 days after inoculation. (Magnified, × 1⅛.) FIG. 2.—Lower surface of Chili leaf 93 days after spraying with sporiferous suspension from fruit strain, showing sparse primary infection and abundant secondary infection in early macroscopic stages. (Natural size.) FIG. 3.—Elberta twigs: *a*, Control, no infection; *b*, inoculated by spraying with sporiferous suspension from twig strain. Photographed 62 days after inoculation. (Magnified, × 1¾.) FIG. 4.—Diseased Chili twig 128 days after spraying with sporiferous suspension from fruit strain, showing abundant primary and secondary infection. (Reduced, × 4/5.) FIG. 5.—Chili twig from control paralleling the inoculation shown in figure 4; no infection. Photographed 128 days after the beginning of the experiment. (Reduced, × 4/5.)

each source of infection, while six, similarly treated but not inoculated served as controls. On June 6 this experiment was duplicated.

Results from series inoculated on May 29.—Two fruits inoculated with the fruit strain of *Cladosporium carpophilum*, two inoculated with the twig strain, and one control fell prematurely. On Sunday, August 2, before final results were available, the remaining fruits of this and the succeeding series, in spite of notices and experimental labels, fell victims to the gastronomic proclivities of trespassers. The earlier results, however, were sufficient to be of material value.

On one of the fruits inoculated with the twig strain of the fungus, eight scab lesions were barely visible on August 1, though no macroscopic infection could be observed on July 25.

On one of the fruits inoculated with the fruit strain, very early macroscopic stages of infection were observed on July 25, while 16 definite lesions were evident on August 1.

The remaining inoculated areas bore no definite macroscopic lesions on August 1, though their appearance strongly suggested the presence of abundant infection in incipient stages.

No evidence of the disease was observed upon any controls or uninoculated fruits, lesions appearing only on inoculated areas.

Results from series inoculated on June 6.—On July 25 no infection was evident. On August 1 scab lesions were discernible on one of the fruits inoculated with the twig strain of the fungus, while the appearance of the inoculated areas generally suggested the presence of incipient infection. The controls showed no evidence of infection.

REISOLATION OF THE FUNGUS.

Thorough microscopic examinations showed that *Cladosporium carpophilum* was uniformly associated with the lesions induced by inoculation. The fungus was reisolated by the poured-plate method and found to possess the typical morphological and cultural characters of *C. carpophilum*.

CONCLUSIONS.

These experiments show (1) that *Cladosporium carpophilum* from pure cultures of single-spore strains isolated from scab lesions on peach twigs or fruit is capable of causing typical and abundant infection upon peach fruit; (2) that, in like manner, this fungus taken directly from twig lesions is capable of producing the disease upon the fruit; (3) that the period of incubation of the fungus upon the fruit may vary from 42 to 77 days, very early macroscopic evidences of the disease sometimes appearing within a slightly shorter period; (4) that the presence of the nutritive solution used apparently hindered infection; and (5) that, under the conditions of these experiments, the three superficial fungi tested are not pathogenic to peach fruit.

Twig and Leaf Inoculations.

Preliminary experiments made in 1913 showed clearly that under field conditions where the disease is prevalent, the chief difficulties attending twig and leaf as well as fruit inoculations are (1) the abundance of natural infection and (2) the difficulty of securing at will conditions favorable for infection. These obstacles were satisfac-

torily overcome (1) by conducting the experiments upon clean young trees and nursery stock in a section (Madison, Wis.) in which peach scab has not been observed to occur naturally, and (2) by using potted trees which could be placed at will under controlled conditions and by constructing moist compartments about young trees in the field.

METHOD OF INOCULATION.

The inoculations, unless otherwise stated, were made upon potted 1-year-old nursery trees which had been cut back to whips, from which vigorous young branches developed in the normal fashion in the spring. The sources of inoculation were 10-day-old to 20-day-old Lima-bean agar cultures of single-spore strains of *Cladosporium carpophilum* isolated, respectively, from the fruit, twigs, and leaves of the peach. In each experiment, parallel germination tests demonstrated the viability of the spores used. The sporiferous suspensions were prepared with sterile distilled water, as in the case of the fruit inoculations, and were applied either as spray by means of sterile De Vilbiss atomizers or by means of clean new camel's-hair brushes. Each series was adequately controlled by plants treated in every way like those inoculated except that sterile distilled water was substituted for the sporiferous suspensions. Just after inoculation the experimental plants were placed in a practically saturated atmosphere in a specially constructed moist compartment in the greenhouse, and 2 to 10 days later they were transferred to the pathological garden, where the pots were sunk to the level of the soil. In order to obtain data regarding the spread of the disease in the field, the plants were arranged in line, according to the sequence of their experimental numbers, being placed far enough apart to avoid contact. They were carefully cultivated and noted at frequent intervals throughout the season. The results are briefly outlined below (Pl. VI, figs. 1 to 5).

EXPERIMENT 1, MAY 22, 1914.[1]

Sources of inoculation.—Cladosporium carpophilum: (*a*) Fruit strain, (*b*) twig strain; both from 13-day-old cultures.

Methods.—This experiment was conducted in the pathological garden on 3-year-old Elberta trees, numbered 851 to 854, which had been cut back to whips and had put out numerous vigorous shoots, averaging about 6 inches in length. The inoculations, except No. 854, were made by spray. The treatments were: No. 851, control; No. 852, twig strain; No. 853, fruit strain; No. 854, twig strain. On three branches of No. 854 only the upper surfaces of the leaves were inoculated, and on three others only the lower surfaces, the sporiferous suspension being applied with a clean new camel's-hair brush. The twigs bearing these leaves were also inoculated. Each experimental tree was covered by a large bell jar or a specially constructed glass box. These devices were lined with wet filter paper and blocked up on temporary platforms. In each of these moist compartments a jar of water maintained a high humidity. On the afternoons of May 23 and May 24 the trees were sprayed lightly with sterile

[1] For further details of each experiment, see the methods of inoculation previously described.

distilled water, care being taken to allow no dripping. On May 29 the glass contrivances were removed.

Results.—On June 20, 29 days after inoculation, abundant infections were barely macroscopic on the twigs and on the under surfaces of the leaves of Nos. 852, 853, and 854, with the exception of those leaves of No. 854 which were inoculated only upon their upper surfaces. These and the control plant, No. 851, developed no signs of infection during the entire season, the last observation being made on October 18. The progress of the disease is best followed in a typical example, as No. 854b. On the inoculated twig surface on June 20 occasional infections were barely visible. On July 1 about 20 infections less than 1 millimeter in diameter were observed. On July 10 over 30 lesions were definitely visible, their diameters varying from one-half to 2 millimeters. On July 17, 46 lesions were counted, the maximal diameter being 3 millimeters. During this period and subsequently the twig grew very rapidly, and bark formation began early. Consequently, the lesions developed but little further and gradually lost their identity as the season progressed. Normally, however, it should be remembered, peach twigs of older trees do not cork over during their first season's development, and on such wood the scab lesions may continue to enlarge during the following season. The progress of the disease on the leaves closely paralleled that on the twigs, except that the lesions were considerably more numerous, over a hundred frequently developing upon a single leaf.

EXPERIMENT 2, JUNE 6, 1914.

Sources of inoculation.—*Cladosporium carpophilum:* (*a*) Fruit strain, (*b*) twig strain, (*c*) leaf strain; all from 20-day-old cultures.

Methods.—Three potted 1-year-old Elberta trees of the type previously described were thoroughly sprayed, respectively, with the three sporiferous suspensions. Two others were inoculated with the fruit strain upon (*a*) the upper and (*b*) the lower leaf surfaces, respectively, the sporiferous suspension being applied by means of a camel's-hair brush. Two controls were sprayed with sterile distilled water. The experiment was duplicated on Chili trees of the same type. Immediately after treatment the trees were placed in the moist compartment in the greenhouse. After three days they were sprayed lightly with sterile distilled water, and five days later they were removed to the field.

Results.—On the twigs and on the lower surfaces of the leaves of the trees sprayed with the fruit and twig strains of the fungus, abundant infection was noted on July 10, 34 days after inoculation. The infections had probably been visible for several days. The lesions increased rapidly in number throughout July. The twig lesions developed slowly throughout the season, attaining a maximal diameter of 6 mm. by October 18. In September and October scattered secondary infections appeared upon the younger wood. The leaf infections typically developed as mere superficial flecks, averaging 1 to 2 mm. in diameter. In many cases, however, the leaf lamina above these flecks became yellowed, and the most severely affected leaves fell in August and September. In September and October scattered secondary infections developed, both on old leaves and on foliage which was produced after the inoculations were made.

On the trees inoculated with the leaf strain of the fungus no disease was observed until July 24, when occasional lesions were noted on the twigs and on the lower surfaces of the leaves. Little further evidence of disease developed until the latter part of the season, when a limited amount of secondary infection of the type above described appeared. The sparseness of infection from this source is attributed to the fact that this strain of the fungus sporulates much less vigorously than the others used. The spores in the suspension with which these inoculations were made were observed to be relatively sparse and to germinate with less than normal vigor. Since these characteristics are not common to all strains of *Cladosporium carpophilum* isolated from peach leaves, it is unfortunate that only this strain was available for these experi-

ments. However, the pathogenicity of other leaf strains was clearly proved in subsequent experiments.

On the leaves inoculated only on their upper surfaces no primary infection developed, with the exception of four lesions which appeared, closely grouped, at the margin of one leaf. This infection clearly occurred on the lower surface, and was probably due to chance inoculation, such as might occur should a drop of the sporiferous suspension accumulate at the margin of the leaf and extend over the edge. While great care was taken to avoid mischance of this kind, as is attested by the fact that only one other such case was observed throughout the season's work, it is obviously impracticable to secure uniformly perfect results from extensive series of experiments of this type. In September and October occasional secondary infections appeared upon the under surfaces of the leaves of these plants.

Abundant disease developed on the lower surfaces of the leaves which were inoculated on these surfaces only. Its development paralleled that on the corresponding sprayed plants.

On the four controls no disease developed, with the exception of occasional late secondary infections upon the leaves and young wood of the plant which was placed about a foot from one of the most severely infected trees of the series. This infection did not become evident until October. The fact that the next control plant, about a foot farther from the source of infection, developed no disease is of significance in relation to methods of spore dissemination, which will be discussed later.

EXPERIMENT 3, JUNE 22, 1914.

Source of inoculation.—Cladosporium carpophilum: Twig strain, from a 14-day-old culture.

Methods.—The inoculations were made upon potted Chili trees of the type previously described. Only the upper surfaces of the leaves of one tree were inoculated by spray, while only the lower surfaces of the leaves of another were similarly treated. A third plant was sprayed with sterile distilled water as a control. The subsequent treatment of the experimental plants paralleled that of the preceding series.

Results.—The leaves inoculated upon their upper surfaces developed no infection, with the exception of several closely aggregated lesions on the lower surface near the margin of one leaf. This infection clearly occurred upon the lower surface and was doubtless of similar origin to the parallel case discussed under experiment 2. On the leaves inoculated upon their lower surfaces, abundant infection was noted on July 17, 25 days after inoculation. The lesions had probably been visible several days. On July 24 the lesions had increased materially in number and size, scores of infections frequently occurring on individual leaves. By the end of September most of the worst affected leaves had fallen. No infection had become visible upon the control plant when it was last examined on October 18.

EXPERIMENT 4, JULY 2, 1914.

Sources of inoculation.—Cladosporium carpophilum: (*a*) Twig strain, (*b*) leaf strain; both from 10-day-old cultures.

Methods.—These inoculations were made upon potted Chili trees of the type used in the preceding experiment. One tree was inoculated only upon the upper leaf surfaces with the twig strain of the fungus, another was similarly treated only upon the lower leaf surfaces, and a third on both surfaces of the leaves. Very young and mature leaves were separately marked and noted. Another plant was inoculated with spray from the leaf strain of the organism, while two others were sprayed with sterile distilled water as controls. The experimental plants were subsequently accorded treatment similar to that of the preceding series.

Results.—When the last notes were made on October 18, no infection had become visible upon the leaves inoculated only upon their upper surfaces. Those inoculated upon the lower surfaces or upon both surfaces developed abundant infection of the

usual type, always on the lower surfaces. No marked difference was observed in the results from inoculations upon the very young and the mature leaves. Sparse infection developed upon the leaves of the tree inoculated with the leaf strain of the fungus, though none was found upon the twigs. No disease developed upon the controls.

EXPERIMENT 5, JULY 11, 1914.

Sources of inoculation.—Cladosporium carpophilum: (*a*) Fruit strain (isolated from an overwintered scabbed peach at Madison, Wis., May 11, 1914); (*b*) twig strain; (*c*) leaf strain; all from 17-day-old cultures.

Methods.—The experimental trees were potted Chili. One was inoculated by spray with the fruit strain and one with the twig strain, while two were similarly treated with the leaf strain. Three other plants were inoculated upon marked areas with the twig strain, one upon the upper surfaces, one upon the lower surfaces, and one upon both surfaces of the leaves. The areas to be inoculated were surrounded by circles of india ink, and the sporiferous suspension was applied in small drops by means of a camel's-hair brush. The ink was allowed to dry before the inoculations were made. Two plants were sprayed with sterile distilled water as controls.

Results.—On the trees inoculated by spray with the fruit, twig, and leaf strains, the disease developed typically and abundantly upon the lower surfaces of the leaves and rather sparsely upon the twigs. The leaf strain occasioned slightly less infection than the others, but materially more than in similar preceding tests. This increase was probably due to the fact that special care was taken to have an abundance of spores in the suspension used for this inoculation. On September 29 the tree inoculated only upon the upper surfaces of the leaves showed no infection. On the tree inoculated only upon the lower leaf surfaces, 14 of 29 inoculated areas showed infection. On the remaining inoculated plant, 66 of 98 inoculated areas on the lower surfaces of the leaves showed infection, while no disease was evident upon 93 similarly treated areas upon the upper surfaces. No infection was observed except on inoculated areas. The control plant developed no evidence of infection.

REISOLATION OF THE FUNGUS.

Numerous microscopic examinations showed that *Cladosporium carpophilum* was uniformly associated with the lesions produced by inoculation. The fungus was reisolated from twig and leaf infections induced by the fruit, twig, and leaf strains, respectively. The morphological and cultural characters of the reisolated strains were typical of *C. carpophilum.*

CONCLUSIONS.

These experiments show (1) that *Cladosporium carpophilum* from cultures of single-spore strains isolated from scab lesions on (*a*) fruit, (*b*) twigs, or (*c*) leaves of the peach is capable of producing abundant typical infection upon peach twigs and leaves; (2) that natural infection of the leaves occurs chiefly, and apparently exclusively, upon the lower (dorsal) surfaces; (3) that young or mature leaves may be abundantly infected; (4) that the period of incubation for leaf infection may vary from 25 to 45 days, and probably more, depending upon conditions; (5) that the period of incubation for twig infection approximates that for leaf infection; and (6) that under favorable conditions secondary twig and leaf infections may appear in the latter part of the summer.

LIFE HISTORY OF THE CAUSAL ORGANISM IN RELATION TO PATHOGENESIS.

In order to trace clearly the detailed life history of the parasite in relation to pathogenesis, it is necessary first to follow carefully the seasonal development of the disease under field conditions. This will now be briefly outlined.

SEASONAL DEVELOPMENT OF THE DISEASE.

ON FRUIT.

The first fruit infections of the season usually become evident shortly prior to the ripening period of such early varieties as the Carman. The early varieties usually show the first general infection, while the late-maturing fruits, which are usually subject to severe attacks of scab, frequently show little macroscopic evidence of the disease until several weeks later. This is probably due, in large measure at least, to the fact that infection is first mechanically hindered and later masked by the hairy thatch of the young peach, becoming visible on early varieties rather suddenly with the lightening of this covering as the fruit rapidly expands prior to maturity. The records upon which this statement is based are outlined as follows:

Supporting records.—At Cornelia, Ga., in 1912 and 1913, the peach trees were in full bloom during the last days of March. The Carmans were harvested during the first week of July, while the Elbertas ripened about a month later.

In 1912 the first scattered fruit infections were noted on unsprayed Carmans, Belles, and Elbertas on June 15, though the lesions had probably been visible for several days. On June 17, 19, and 25 the disease was increasingly evident, especially upon the rapidly maturing unsprayed Carmans, where it was quite conspicuous by July 4. As was emphasized in examining over 20,000 Carman fruits in taking results on spraying experiments, this early infection occurred almost exclusively about the depressions surrounding the peduncles and upon the closely adjacent wettable surfaces. On later varieties the disease became increasingly conspicuous until the maturity of the fruit, the lesions frequently becoming confluent over large patches.

In 1913 the course of the disease was somewhat modified by a severe spring drought, which occurred in April and early May. Scattered lesions were observed upon Carmans and Belles on June 14, while the first infections on Elbertas were noted on June 25. Only occasional infections were observed until July 1, when the disease was conspicuous upon unsprayed Carmans. On Elbertas little infection was evident until the middle of July, after which the disease became increasingly abundant.

ON TWIGS.

Scattered twig lesions usually become evident at about the time the disease appears upon the fruit. Generally, however, they do not appear abundantly until late summer and fall. They pass the winter in various stages and complete their development during the second season.

Supporting records.—In Georgia, in 1912, the first scattered twig infection was noted on unsprayed Elbertas at Fort Valley on June 12. At Cornelia it was not observed until July 4, though it probably had been visible for more than a week.

Twig lesions remained quite scarce, however, throughout July, but began to appear in greater numbers during early August. On August 13 they were fairly abundant upon unsprayed trees in low places. On August 20 a dozen twigs were tagged and noted as to scab development. On September 10 numerous additional infections were evident on these twigs, while the older lesions had enlarged perceptibly.

In 1913 sparse twig infection was observed at Cornelia on July 14. In early August these lesions became much more abundant, and the subsequent development of the twig disease closely paralleled that of the preceding season.

It was planned to obtain exact data concerning the development of twig lesions during their second season by following closely the development of the disease on the twigs tagged and noted on August 20, 1912. Unfortunately, however, the experimental trees were "dehorned" before the writer returned to Georgia in 1913. Nevertheless, field observations in 1912 and 1913 showed beyond question that lesions may pass the winter in any macroscopic stage of development and continue their development during the next season. It was evident, further, that many late infections do not become visible until the following spring.

In the springs of 1912 and 1913 twig lesions occurred generally and abundantly. It was difficult to find a Summerour twig which was free from infection, while, in many instances, the lesions were so abundant as to become confluent.

ON LEAVES.

Owing to the inconspicuous nature of the leaf disease as it occurred under field conditions in Georgia and to its wide variance in appearance from previously published descriptions, the leaf lesions were not identified until 1913. Therefore, the writer has not had the most favorable opportunity of following closely their seasonal development under natural orchard conditions. Inoculation experiments have shown, however, that young or mature leaves may readily be infected and that the period of incubation on the leaf closely approximates that on the twig. It is evident, therefore, that the occurrence of the leaf disease should parallel that on the twigs. Such field observations as are available accord with this view.

Supporting records.—Leaf infections were first observed at Cornelia on August 21, 1913, though they evidently had been visible for some time. The lesions were not very abundant, but increased in number as the season progressed. In late September and October they were quite abundant, though inconspicuous, upon the under surfaces of unsprayed Summerour leaves.

On August 6, 1915, abundant infection was observed upon the lower surfaces of Elberta leaves at Chevy Chase, Md. The appearance of the lesions indicated that they had been visible for at least three or four weeks.

PRODUCTION OF CONIDIA.

Throughout the seasons of 1912 and 1913 the occurrence of conidia was closely followed by means of frequent examinations of scab lesions (*a*) directly from the field and (*b*) from moist chambers.

ON FRUIT.

Conidia are usually borne upon the fruit in the earliest macroscopic stages of infection and may be produced under favorable conditions

throughout the development of the lesions. Sporulation upon the fruit, therefore, may be very abundant, but its duration is relatively brief, especially in the case of early varieties.

Supporting records.—In Georgia in 1912 and 1913, conidia were usually found in greater or less abundance upon fruit lesions as soon as the infections became macroscopic, and under favorable conditions spore production occurred abundantly throughout the earlier stages of development of the spots. With the advent of the heat and drought of midsummer and late summer, however, sporulation upon the older lesions, especially those in which the diseased areas had been cut off from the surrounding normal tissues by cork layers, became practically or entirely nil.

ON TWIGS.

Conidia may be produced upon twig lesions, under favorable conditions, as soon as infection becomes visible. Usually they are borne only sparsely during the season in which the infection occurs. In the following spring, under favorable conditions, spores ordinarily appear in abundance upon overwintered twig lesions soon after the blossoming period of the peach. Subsequently, during moist periods throughout the spring and early summer they are borne profusely from this source. Usually, however, under the conditions of northern Georgia, sporulation from these lesions diminishes rapidly in midsummer and becomes practically nil in late summer. Spores may thus be produced in considerable abundance upon twig lesions at any time during the growing period of the host.

Supporting records.—Under field conditions, during their first season's development, twig lesions uniformly produced conidia very sparingly. In some cases spores were sparsely evident microscopically in the earliest macroscopic stages of infection; in others, the lesions produced only occasional conidiophores and conidia in the course of the summer. In practically all such cases observed, the conidiophores were produced singly, and only rarely were they abundant in the field. In moist chambers, however, spores were borne abundantly upon such lesions, though the conidiophores were not borne in tufts.

With the advent of spring, conidiophores appeared in abundant macroscopic olive-green tufts upon overwintered lesions. In 1913 these were first observed on April 1, when the trees were in full bloom. Careful microscopic examinations, however, revealed no conidia. Occasional conidia were found upon such hyphæ on April 11, while on April 15 and 18 they were observed in slightly increased numbers. On account of phenomenally dry weather, spore production was very sparse throughout the spring; but the fact that it would have been more abundant under favorable conditions was demonstrated by the abundant sporulation which occurred when twig lesions were held over night in a moist chamber. After the rains of early summer, spores were observed in abundance. In midsummer and late summer, however, they became more and more sparse on the overwintered lesions and more numerous on the current year's infections. As late as August 21 conidia were observed in fair abundance upon lesions on the old wood.

ON LEAVES.

Conidia may occur upon the leaves as soon as the infection is evident, and sporulation may continue under favorable conditions throughout the development of the lesions. Inasmuch as most

abundant leaf infection appears late in the season, conidia from leaf lesions are most plentiful in late summer and fall. In the cases observed by the writer, the aggregate sporulation from lesions on the leaf appeared to be much less than that from twig or fruit infections.

Supporting records.—From August 21, 1913, when leaf lesions were first observed in Georgia, until the end of the season, they bore spores in greater or less abundance. In the inoculation experiments at Madison, Wis., conidia were usually present when the lesions became macroscopic. The amount of sporulation and its period of duration upon the individual lesion appear to vary greatly with conditions.

VIABILITY AND LONGEVITY OF CONIDIA.

Hundreds of germination tests conducted during the seasons of 1912, 1913, and 1914 showed that freshly produced, normal conidia from fruit, twig, or leaf lesions are capable of germinating in sterile distilled water, rain water, or a large variety of nutrient solutions. The frequent paucity of germination from miscellaneously collected field material indicated, further, that under unfavorable conditions the viability of spores may diminish rather rapidly with age. This, however, seems to be of relatively little practical significance, since fresh conidia may be produced with the advent of conditions favorable for infection. The summarized results of a few typical germination tests are given in Table VI.

TABLE VI.—*Summarized results of typical germination experiments with conidia of Cladosporium carpophilum from field material at Cornelia, Ga., in 1913 and at Madison, Wis., in 1914.*[1]

Serial No.	Date.	Variety.	Source of lesion.	Estimated germination in 3 days (per cent).	
				Sterile distilled water.	1 per cent prune decoction.
438	July 1, 1913	Belle	Fruit	50	90
492	July 22, 1913	Elberta	do	10	15
505	July 24, 1913	do	do	30	
507	July 26, 1913	do	do.[2]	20	90
536	Aug. 22, 1913	Fox	do	0	0
275	Apr. 13, 1913	Elberta	Overwintered twig	80	99
374	June 7, 1913	Belle	do.[2]	95	99
420	June 21, 1913	Elberta	do.[2]	50	70
474	July 7, 1913	do	do.[2]	10	10
494	July 27, 1913	do	do.[2]	30	30
558	Oct. 7, 1913	Summerour	Current year's twig	50	95
566	Oct. 9, 1913	do	do	40	95
731	Nov. 1, 1914	Chili	do	95	99
660	Oct. 7, 1913	Summerour	Leaf lamina[2]	60	95
668	Oct. 9, 1913	do	Petiole[2]	40	95
670	Oct. 23, 1913	do	do	60	60
725	Oct. 9, 1913	do	Leaf lamina	95	99

[1] These germination tests were made in open drops upon clean sterile glass slides in moist chambers and incubated in diffuse light in the laboratory. Unless otherwise stated the spores were secured from fresh field material.

[2] Spores secured from material which had been held in moist chamber 2 to 4 days.

A longevity experiment is briefly reported below.

Experiment 1.—On April 16, 1915, abundantly sporulating 17-day-old cultures of a twig strain of the fungus on steamed bean pods were removed from the culture tubes

and placed in dry cloth-covered jelly glasses (*a*) in the laboratory, where the temperature ranged from 18° to 25° C., and (*b*) in the pathological garden in a covered, latticed compartment of the type commonly used for housing meteorological instruments. The cultures rapidly became air dry. The conditions precluded the further growth or sporulation of the fungus. Germination tests were made at intervals. The results, which are summarized in Table VII, show that in each series a considerable percentage of spores remained viable for more than three months. Had the spores been exposed to wetting, however, it must be remembered that they would have germinated with the advent of favorable conditions. Thus, it is not to be expected that conidia ordinarily retain their viability for long periods.

TABLE VII.—*Summarized results of a longevity test of conidia of Cladosporium carpophilum from cultures, Madison, Wis., April 16 to October 25, 1915.*

Serial No.	Date of test.	Place of storage of culture.	Estimated germination in 3 days (per cent).	
			Sterile distilled water.	1 per cent prune decoction.
786	Apr. 16, 1915	Laboratory	99	99
787	do	Garden	99	99
864	June 3, 1915	Laboratory	50	90
862	do	Garden	60	90
996	July 23, 1915	Laboratory	15	90
994	do	Garden	10	90
1004	Oct. 25, 1915	Laboratory	0	0

DISSEMINATION OF CONIDIA.

Studies planned to give insight into (1) the conditions under which conidia of *Cladosporium carpophilum* are detached from the parent fungus and (2) the more important methods by which they are disseminated are briefly outlined as follows:

EXPERIMENTAL WORK.

Experiment 1.—Colonies of the fungus were grown in tubes on steamed bean pods over a bean decoction in such position that spores which might be abstricted or abjected would fall into the liquid below and germinate. The experiment was run in quadruplicate and continued for six weeks. The colonies developed vigorously and sporulated profusely, but the decoction below remained sterile. After six weeks one of the cultures was shaken so that the liquid came in contact with the colony. Within three days the decoction was conspicuously clouded and darkened by the development from myriads of spores which had been detached.

This experiment was repeated with like results, while similar tests were made with a variety of other media. The results were uniformly confirmatory.

Experiment 2.—On April 19, 1915, severely infected peach twigs were placed in moist chambers. On April 23 a number of these twigs bearing abundantly sporulating lesions were placed (*a*) in moist chambers and (*b*) in dry chambers 1 cm. above glass slides smeared with glycerin. These slides were examined microscopically at intervals for two days. No spores were found.

Experiment 3.—Sections of lesions were placed under the low power of the microscope in such position that tufts of spores could be observed. Currents of air were passed over this material by means of an aspirator. The conidiophores in certain cases

could be seen to sway, but the spores remained in place. When a drop of water was brought in contact with the spores, however, they quickly became detached.

Experiment 4.—An abundantly sporulating culture on a section of a steamed bean pod was placed in a glass tube, 2 cm. in diameter and 30 cm. long, about 2 cm. from the distal end, in such fashion that no part of the colony touched the glass. A glass slide smeared with glycerin was placed about 1 cm. from the opening of the distal end of the tube in position to catch particles which might be blown through. For about 30 seconds a strong current of air was aspirated into the proximal end of the tube by means of a hand bellows. While no attempt was made to measure the velocity of the air current, it was strong enough to move the section of wet bean pod several millimeters. It was thought to be at least the equivalent of the strongest wind ordinarily affecting an orchard. Subsequent careful microscopic examination of the slide showed that only occasional spores were present. In most of these cases the conidiophores, rather than the spores, had been detached.

Experiment 5.—The culture used in the preceding experiment was gently sprayed with distilled water by means of an atomizer, in such fashion that only the finest particles of spray fell upon it. When a drop of water accumulated at the bottom of the pod it was examined microscopically and found to contain myriads of conidia.

Experiments 6 and 7.—Experiments 4 and 5 were repeated, with confirmatory results.

Experiment 8.—On April 23, 1915, a peach twig about 10 cm. long, similar to those used in experiment 2 and bearing more than 30 abundantly sporulating scab lesions, was clamped about the base by a cork which was inserted in a bottle of water. Thus, the twig was kept fresh and turgid, with about 7 cm. of its length exposed. In this condition it was placed out of doors in a brisk wind for two hours. A glass slide smeared with glycerin was placed 1 cm. away from the twig upon the leeward side, in position to catch spores which might be blown off. At the end of the experiment a careful microscopic examination of the slide revealed only occasional spores of *Cladosporium carpophilum*.

Experiment 9.—The twig used in the preceding experiment was placed in the aspirating apparatus employed in experiment 4, in such position that it did not touch the surface of the tube. The aspirator was operated as in experiment 4. Only occasional spores could be found upon the glycerined slide, though they were slightly more abundant than in the preceding test.

Experiment 10.—The twig used in the preceding test was sprayed in the manner described in experiment 5. The drops of water which accumulated contained myriads of conidia.

Experiment 11.—The twig used in the preceding test was allowed to dry over night in the laboratory. The next day it was put in the aspirating apparatus and treated as in experiment 9. The results were not materially different from those of experiment 9, though the number of conidia caught was very slightly increased.

Experiments 12 to 15.—Experiments 8 to 11 were repeated, with confirmatory results.

The results of these and of other similar experiments show: (1) That the dry conidia of *Cladosporium carpophilum* are not normally abscised or abjected; (2) that in a dry or humid atmosphere they remain persistently attached to the parent fungus; (3) that in contact with water they promptly become detached; (4) that even after spores have been detached by wetting the twigs they are not readily disseminated by wind after a period of drying. Thus, the evidence strongly indicates that under orchard conditions wind may be expected to play only a minor rôle in the dissemination of conidia, while

meteoric water appears to be peculiarly well adapted to the performance of this function.

OBSERVATIONAL DATA.

Careful field observations extending through several seasons yielded results which accord thoroughly with those of the preceding experiments. Examinations of large numbers of typically affected fruits, usually upon midseason and late varieties where the disease had reached its full development, showed two distinct types of infection, viz, (1) abundant infection extending from the depressions about the peduncles well over the wettable surfaces of the fruits and (2) sparse, scattered infections rather uniformly distributed over the wettable surfaces. In the former type, the lesions, numbering usually about 200 to 300, were uniformly most abundant about the attachment of the peduncles and over the proximal portions of the wettable surfaces of the fruits, frequently becoming confluent over considerable areas, but normally occurring less abundantly toward the distal portions. In the latter type the lesions usually numbered less than 50, while their position showed no relationship to the peduncles. Fruits of the former type were, almost without exception, borne in close proximity to twig lesions, in such position that spores could be washed down the twigs to the peduncles and thence over the wettable surfaces of the fruits. Those of the latter type were as uniformly borne in positions which precluded this method of dissemination. When infection is very severe, as upon badly diseased late varieties, these types have been observed to merge into each other.

In order to secure definite data, observations were made at Cornelia, Ga., on July 23, 1913, upon 50 fruits selected at random from a large number of trees in a badly diseased unsprayed Elberta orchard. Notes were made concerning the approximate number of infections, the areas upon which they occurred, the areas upon which no infection occurred, the proximity of lesions upon the subtending twigs, and the facility with which spores from the twig lesions might be transferred to the fruits by means of meteoric water. The results are summarized in Table VIII.

Certain striking relationships which can not be brought out in the table are here set forth:

Notes supplementing Table VIII.—No. 34 was borne in a horizontal position upon a short spur, with no chance of infection by means of water-borne spores from the subtending twig. About 5 cm. above the wettable surface of the fruit, however, numerous lesions occurred upon a horizontal twig. Thus, it is obvious that the abundant infection was induced by water-borne spores from this source.

Nos. 38, 37, 36, and 35 occurred, in the order here given, almost in contact (peduncles at intervals of about 10 cm.) upon a single twig which sloped at an angle of about 15°, with the distal end lower. The striking differences in infection are worthy of special emphasis. In the case of No. 38, the fruit nearest the base of the twig with no chance

of infection by water-borne spores from lesions upon the subtending twig, only about 25 uniformly scattered infections occurred. In striking contrast, the three fruits immediately adjacent, with excellent conditions for infection of this type, developed about 225 lesions each. Instead of being uniformly scattered over the wettable surfaces of the fruits, as would be expected had they resulted from wind-blown spores, these lesions were massed about the peduncles and over the proximal portions of the wettable surfaces, gradually becoming less abundant toward the apices. Again, had the infecting spores been wind blown, the infection should have been practically equally prevalent and similarly situated upon the four fruits in question.

TABLE VIII.—*Summary of observations concerning the occurrence and location of scab lesions on unsprayed Elberta fruits and twigs in relation to spore dissemination, Cornelia, Ga., July 23, 1913.*

[The observed infections were on the wettable surfaces of the fruits, while the protected surfaces were not infected.]

Fruit No.	Estimated lesions.	Distribution of lesions.	Distance from peduncle to nearest lesion on subtending twig.	Facilities for infection by water-borne spores from subtending twig.	Fruit No.	Estimated lesions.	Distribution of lesions.	Distance from peduncle to nearest lesion on subtending twig.	Facilities for infection by water-borne spores from subtending twig.
	Number.		*Cm.*			*Number.*		*Cm.*	
1	250	Aggregated	0.5	Excellent	26	25	Scattered	16	Poor.
2	250	do	.5	do	27	250	Aggregated	.5	Excellent.
3	20	Scattered	[1]	None	28	10	Scattered	20	Poor.
4	225	Aggregated	1	Excellent	29	250	Aggregated	.5	Excellent.
5	225	do	.5	do	30[3]	12	Scattered	[1]	None.
6	250	do	1	do	31	250	Aggregated	.5	Excellent.
7	12	Scattered	[1]	None	32	40	Scattered	4	Poor.
8	250	Aggregated	.5	Excellent	33	60	do	[1]	None.
9	12	Scattered	[1]	None	34	200	do	[1]	Do.
10	250	Aggregated	.5	Excellent	35	225	Aggregated	1	Excellent.
11	250	do	.5	do	36	225	do	1	Do.
12[2]	20	Scattered	2	None	37	225	do	1	Do.
13	225	Aggregated	.5	Excellent	38[3]	25	Scattered	4	None.
14	225	do	.5	do	39	250	Aggregated	.25	Excellent.
15	250	do	.5	do	40[3]	20	Scattered	[1]	None.
16	20	Scattered	4	None	41[2]	25	do	[1]	Do.
17	250	Aggregated	.5	Excellent	42	250	Aggregated	.5	Excellent.
18	250	do	.5	do	43[2]	10	Scattered	[1]	None.
19	250	do	.5	do	44	100	Aggregated	1	Excellent.
20[2]	25	Scattered	6	None	45	250	do	.25	Do.
21	25	do	6	Poor	46[3]	12	Scattered	[1]	None.
22	250	Aggregated	.5	Excellent	47	250	Aggregated	1	Excellent.
23	250	do	.25	do	48[2]	25	Scattered	[1]	None.
24	250	do	1	do	49	225	Aggregated	.5	Excellent.
25[2]	12	Scattered	16	None	50	30	Scattered	[1]	Do.

[1] No lesion on subtending twig.
[2] Fruit, apex up, borne upon a short spur.
[3] Fruit in favorable position for infection by water-borne spores from lesions on subtending twig, but not such lesion present.

These data show (1) that every badly diseased fruit observed developed under excellent conditions for infection by means of conidia from twig lesions; (2) that in all cases where conditions were favorable for the passage of water-borne spores from lesions on the subtending twigs down the peduncles and over the wettable surfaces of the fruits severe infection resulted, the disease uniformly appearing most abundantly on the areas obviously most subject to this type of dissemination; (3) that in all cases where conditions precluded this type of dissemination only sparse infection occurred, the lesions being miscellaneously scattered over the wettable surfaces of the fruits in a

manner suggesting infection from rain-beaten or wind-blown spores; and (4) that even under these severe conditions no infection occurred upon the protected surfaces of the fruits, doubtless due to the fact that these areas are rarely, if ever, thoroughly wet during the more important periods of fruit infection, and consequently both the transfer of spores to such areas and the subsequent development of the fungus are practically precluded.

CONCLUSIONS.

From the evidence presented, it appears to be conclusive that a large majority of fruit infections result from water-borne spores from lesions on the subtending twigs. Considerable dissemination must obviously be accomplished by meteoric water which drips or spatters from spore-bearing areas. Wind dissemination evidently occurs to a limited degree, especially in cases where spores are detached from the parent fungus by chance mechanical agencies, as by the rubbing together of organs of the host plant or by the impact of wind-blown sand particles. It is altogether probable that other general agencies of spore dissemination, such as insects and birds, may play some part in spreading the disease, but no evidence of this has been observed. If it occurs, it is certainly of very minor importance, except, possibly, as a means of transferring spores over relatively long distances.

METHOD OF INFECTION.

The exact method by which the fungus penetrates the cuticle of the various affected organs of the host has not been conclusively determined. While the solution of this problem is necessary to a full knowledge of pathogenesis, the attendant difficulties are such that this would have required the expenditure of more time than would be justified by its importance to this paper. Certain observations and experiments in this connection, however, seem to be worthy of record.

The abundance of naturally and artificially induced infection shows conclusively that the penetration of the fungus is independent of wounds. Consequently, it must normally occur through natural openings, directly through the cuticle, or in both of these ways. Since the problem is presented in its simplest aspect in leaf infection, certain studies of leaf penetration were made, as follows:

Experiment 1.—On July 15, 1915, a potted 2-year-old Early Crawford tree bearing abundant foliage in various stages of development was inoculated by spraying with a water suspension of spores from a 15-day-old Lima-bean agar culture of a twig strain of the fungus. The plant was kept in a moist compartment and sprayed daily with sterile distilled water. Marked inoculated leaves in various stages of development were collected daily and placed in stoppered test tubes in a solution prepared by mixing glacial acetic acid and 95 per cent ethyl alcohol in equal parts. After the leaves were thoroughly bleached, their under (dorsal) surfaces were carefully studied microscopically, previous inoculation experiments having shown that the upper

(ventral) surfaces are not infected. The development of the fungus was easily traced. Material collected 48 hours after inoculation showed abundant germination, the tubes averaging 40 to 60 μ in length. No evidence of penetration, however, was observed at this stage. In subsequent collections, which extended over six days, a slow development of the fungus could be traced, but this appeared to be almost entirely superficial. Frequently germ tubes were traced over stomata, but in no case were they observed to enter them. In certain cases, in material collected on the third day and subsequently, slender colorless hyphæ were observed in such positions as strongly to indicate direct penetration of the cuticle, the apical portions being in a slightly lower focal plane than the spores from which they originated. However, the thinness and the delicacy of the cuticle, which on the lower surface of the leaf is usually less than $1\frac{1}{2}$ μ thick, and the fact that the fungus does not penetrate farther into the leaf tissues made it impossible to draw final conclusions from the material at hand. There was no opportunity of extending these studies. These data, however, in conjunction with the fact that penetration through stomata could not put the fungus in its characteristic subcuticular position, leave no reasonable doubt that leaf infection occurs by means of direct penetration of the cuticle.

No special studies of twig and fruit infection have been undertaken. However, since the nature of the surfaces of the very young twigs is so similar to that of the lower surfaces of the leaves, it is to be expected that leaf and twig penetration are of the same type.

In the earliest stages of fruit infection observed in histological preparations, the fungus was found closely appressed to the host cells in the minute depressions surrounding the bases of hairs. These cavities obviously offer exceptionally favorable conditions for infection courts, and it is entirely probable that most fruit infection occurs in this fashion, the development of the fungus being chiefly superficial, in close contact with the cells of the host.

PERIOD OF INCUBATION.

On fruits.—The time which elapses between infection and the macroscopic appearance of fruit lesions has been shown to vary, not only with environmental conditions, but also with the nature and stage of development of the fruit. In the inoculation experiments this period was observed to vary between 42 and 77 days. In nature, with more extreme conditions, it is highly probable that the variations are even greater.

On leaves.—In leaf infection similar variations occur, but they are less marked, since the complicating factor of masking by hairs is eliminated. In the inoculation experiments it was shown that the period of incubation for leaf lesions might vary between 25 and 45 days, and probably more. Under the more extreme conditions of the field, it is likely that the variations are greater.

On twigs.—In the inoculation experiments the period of incubation for twig infections of the early summer closely approximated that of leaf infection. It is evident, however, that great variations in this regard may occur in the case of late twig infections, many of which do not become macroscopic until the following spring.

TIME OF NATURAL INFECTION.

Of fruit.—The inoculation experiments previously reported show that infection may occur from spores applied 10 days after the calyces are shed, but it should be remembered that special precautions were taken to insure the passage of these spores through the difficultly wettable hairy thatch of the fruit. It is evident, however, that such early infection is rare in nature, since (1) the disease may be commercially controlled when the first application of spray is made one month after the petals fall and (2) the interim between this time and the general macroscopic appearance of the disease coincides satisfactorily with the period of incubation of the fungus, as worked out in the inoculation experiments. The chief reasons for this delay appear to be (1) the hindrance of access of spores to the surface of the fruit, due to the difficultly wettable hairy thatch of the peach and (2) the diminution of infection by means of water-borne spores from subtending twigs, due to the upturned position of many fruits during the earlier stages of their development. As the fruits increase in size, the hairy covering becomes thinner and more easily wettable, while, with increased weight, the peaches generally turn downward and become more subject to inoculation by sporiferous meteoric water from infected subtending twigs. Abundant infection usually begins to occur about five to seven weeks after the petals fall and may continue until the fruit matures, but on account of the long period of incubation of the fungus the later infections do not become macroscopically evident.

Of twigs and leaves.—From the results of the inoculation work it is evident that twig and leaf infection may occur whenever viable spores come in contact with tender young twigs or the under surfaces of leaves under conditions favorable for the development of the fungus. Under field conditions in Georgia, however, as is shown by the data given concerning the seasonal development and the period of incubation of the fungus, very little infection occurs on twigs and leaves until several weeks after the petals fall. Subsequently, such infections occur abundantly, with favorable conditions, throughout the season. Important reasons for the fact that the bulk of the twig and leaf infection occurs relatively late are (1) that in the South much of the new wood of the peach tree is formed relatively late and (2) that the conidia borne upon fruit lesions may constitute an important source for infections which, on account of the long period of incubation of the fungus, do not become visible until late in the season.

SOURCES OF NATURAL INFECTION.

Primary.—From the data presented in the preceding topics it is apparent that primary infection results from conidia from overwintered twig lesions. Practically all the fruit infections, especially in the case of early and midseason varieties, come from this source, as

do the earlier infections of twigs and leaves. No other source of infection is known to be available until sporulation occurs on lesions of the current year's production. In northern Georgia this does not usually take place to any considerable degree until early June.

Secondary.—Conidia from lesions of the current year's production constitute the source of secondary infection. On account of the long period of incubation of the fungus, lesions resulting from this type of infection rarely become injurious on the fruit, except, perhaps, on late varieties. On the twigs and leaves, however, as was demonstrated in the inoculation experiments, secondary infections may be very abundant. Under orchard conditions such infections undoubtedly account for a large percentage of the twig and leaf lesions which appear throughout the late summer and fall.

OVERWINTERING OF THE FUNGUS.

In considering the problem of how the fungus passes the winter, three major possibilities demand attention, viz, (1) the overwintering of conidia, (2) the overwintering of the mycelium in dead infected parts, and (3) the overwintering of the mycelium in lesions upon the living host.

Careful studies of infected fruits, twigs, and leaves in late winter uniformly failed to reveal the presence of viable conidia. Furthermore, the evidence furnished by the germination tests previously reported shows conclusively that when exposed under orchard conditions these conidia would not remain dormant and viable over winter. Even if they did pass the winter in minimal numbers, the conditions of infection, as set forth above, would make them a negligible factor in the life history of the fungus.

In the fall of 1913, portions of diseased fruits, twigs, and leaves from Cornelia, Ga., were exposed in the university orchard at Madison, Wis., and allowed to pass the winter. In the following spring conidia were produced in considerable numbers upon the fruit and twig fragments, and the fungus was readily isolated from each of these sources. The leaves, however, were badly decomposed, and the fungus was not identified upon them.

At Cornelia, Ga., during the springs of 1912 and 1913, many overwintered fruits and leaves from trees and from the ground were examined microscopically. The fungus was not definitely identified from any of these sources. It is quite probable, however, that under favorable circumstances the mycelium may survive the winter under orchard conditions upon fallen fruits, twigs, or leaves; but the evidence previously cited seems to prove conclusively that this type of overwintering is of no practical significance in the life history of the fungus.

In connection with this work, careful watch was kept for a possible ascigerous stage of the fungus, but no positive results were secured.

As has been shown in preceding topics, the primarily important overwintering of the fungus is accomplished by the mycelium in lesions on living twigs. Here the organism passes the winter safely, and with the advent of favorable conditions in spring it produces conidia abundantly.

CLIMATE IN RELATION TO THE DISEASE.

Published records from the more important peach-producing districts of the world indicate that scab occurs at its worst in temperate sections where the spring and early summer are moist and the growing season is long, while it is much less prevalent in dry sections or in high altitudes, where the opposite conditions obtain. Likewise, in regions where the disease is abundant it is more prevalent in moist than in dry seasons and on low than on high ground.

In the light of the foregoing life-history studies, the reasons underlying these conditions are evident. Abundant moisture is necessary for spore production, spore dissemination, and infection, while the long growing season increases the period during which these processes may occur.

VARIETIES IN RELATION TO THE DISEASE.

Among writers on this aspect of peach scab, there appears to be a consensus of opinion that varieties differ markedly in the degree in which they are subject to the disease. Selby (1898, p. 221) writes—

> Certain varieties of peaches appear more susceptible to scab than others, just as certain varieties of apples suffer more than others from the apple scab.

Scott and Quaintance (1911, p. 11–12) state—

> In general, the late varieties are much more susceptible than the early varieties. This is due, in part at least, to the fact that the fruit of the late-maturing varieties is exposed to infection over a longer period and the opportunity for the development of the disease is greater.

While the writer has made no detailed study of these varietal differences, field observations and the life-history work previously reported accord well with the views of Scott and Quaintance. In general, the fruit of the earlier varieties, such as the Greensboro, Carman, and Hiley, is relatively lightly attacked. The midseason varieties, such as the Belle and Elberta, may be moderately or severely diseased, depending upon conditions. Late varieties, such as the Heath, Salway, and Bilyeu, are the most severely attacked.

These conditions are partly explained in the light of the life-history studies. The lateness of infection and the long period of incubation ordinarily preclude very seriously injurious development of the

disease before early varieties are harvested. On midseason varieties under conditions favoring the development of the disease, there is time for very serious injury to result. On late varieties the great increase in opportunities for infection and incubation are attended by consequent increment in the severity of the disease. The earlier varieties as a group are thus more properly designated as disease-escaping than as resistant, since they may be quite seriously scabbed when conditions unusually favor the early development of the disease.

While the period of exposure of the fruit to the attack of the fungus appears to be a major factor in these varietal differences, it is evident that other causes are involved. It has been noted that certain varieties growing in adjacent rows and ripening at about the same time have been attacked by scab in very different degrees and that certain of the earlier varieties are commonly more seriously affected than some of those which ripen later (Table IX). It is also a matter of common observation that seedlings are often especially severely attacked. No attempt has been made to investigate the further causes underlying these variations.

At the writer's request Mr. M. B. Waite, Pathologist in Charge of Fruit-Disease Investigations, Bureau of Plant Industry, has prepared a list of important commercial varieties of peaches grown in the Middle States, with estimates concerning the degrees in which they are subject to scab injury in this territory. These estimates, which are based upon more than 25 years of experience and observations extending over all the important peach-producing districts of the area in question, are incorporated in Table IX.

TABLE IX.—*List of important commercial peach varieties, with estimates of the comparative degrees in which they are subject to injury by Cladosporium carpophilum in the Middle States.*

Variety.	Estimated decrease in market value of unsprayed crop due to scab injury (per cent).		Variety.	Estimated decrease in market value of unsprayed crop due to scab injury (per cent).	
	In average seasons.	In bad seasons.		In average seasons.	In bad seasons.
Alexander	25	50	Oldmixon	40	80
Rivers	40	80	Elberta	35	70
Hale Early	15	30	Chairs	35	70
Waddell	30	60	Late Crawford	25	50
Carman	30	60	Edgemont	25	50
Mountain Rose	40	80	Stevens	30	60
Hiley	15	30	Fox (*Fox Seedling*)	25	50
St. Johns	10	20	Smock	40	70
Champion	30	60	Heath	50	90
Early Crawford	15	30	Salway	60	90
Belle	25	50	Bilyeu	70	95
Reeves	35	70	Tennessee	75	100
Stump	30	60			

Supplementary notes by Mr. Waite follow.

Notes supplementing Table IX.—This list gives most of the commonly grown commercial peach varieties of the Middle States in their order of ripening, and comparative estimates of scab injury to unsprayed fruit, in percentage of the value of the crop, in average localities from southern Pennsylvania, Maryland, and Virginia west to Missouri and Arkansas. North of this section, and particularly along the northern limit of peach culture, from New England and New York to Michigan, there is considerable reduction in the severity of the disease. The damage is distinctly less on light, sandy soils than on heavy soils or even on sandy loams. It is greatly reduced at high altitudes. For example, Bilyeu, before the advent of spraying, was considered wholly unfit for commercial planting below 1,500 feet altitude in the Appalachian Mountain belt, on account of its susceptibility to scab, but could be grown successfully at high altitudes. The disease is somewhat more destructive in the Southern States than in the Middle States, and is generally aggravated in moist localities. In arid regions it disappears.

A peach half covered with confluent scab spots, particularly if cracked open, may be considered as without commercial value. A peach badly spotted, with only one-fourth of its area covered, may be considered as of only 50 per cent commercial value in comparison with perfectly smooth fruit. Fruit with even less scab in a season of low prices may be rendered unfit for marketing. With unsprayed trees of Heath, Salway, Bilyeu, Tennessee, and certain seedlings in lower altitudes in the Middle and Southern States it is not rare to have the entire crop rendered commercially worthless by scab.

CONTROL MEASURES.

SPRAYING.

Since the serious economic aspects of peach scab began to be recognized during the early period in the development of Bordeaux mixture, when this newly discovered fungicide was being applied with such marked success in the control of many of the most destructive plant diseases, it is not surprising that the earliest efforts to control this malady consisted almost entirely of spraying experiments with Bordeaux mixture of various formulas. Cobb (1894, p. 386) and Sturgis (1897, p. 271), apparently on a priori grounds, suggested treatments with this fungicide, while Price (1896, p. 840–841) reported decidedly favorable results from three applications of Bordeaux mixture (4–5–50) upon Early China and Mamie Ross. Selby (1898, p. 237–260), in 1895 and 1896, carried out the first extensive spraying experiments, reporting favorable results from the use of Bordeaux mixture. Five years later the same author (1904, p. 67), as the result of seven years' study, states—

> For scab prevention, in addition to one spraying before blossoming with some effective fungicide, recent observations indicate the need of two applications of weak Bordeaux mixture [2–2–50] upon trees in foliage; the earlier of these to be made in northern Ohio about June 15; the second, three to four weeks later.

Although this treatment was efficacious and proved satisfactory in certain sections and under certain conditions, so much host injury resulted that Bordeaux mixture never came into general use throughout the United States as a summer spray for the peach.

While many other spraying experiments were reported during this period and subsequently, no material advance was made until Scott (1907 and 1908), realizing that the copper sprays in their present state of development are too toxic for general application upon peach foliage, sought to develop an efficient fungicide which would be applicable to tender-foliaged plants without serious host injury. He conducted preliminary experiments with self-boiled lime-sulphur and reported very promising results in the control of peach scab. The same author (1909, p. 7–12) carried out further similar experiments and recommended (p. 11–12) self-boiled lime-sulphur treatments for the control of this malady. Scott and Ayres (1910) and Scott and Quaintance (1911) confirmed these results by extensive spraying experiments and gave detailed recommendations for the self-boiled lime-sulphur treatments.

Lewis (1910) conducted peach-spraying experiments in which he used, comparatively, self-boiled lime-sulphur, home-boiled lime-sulphur, Bordeaux mixture, and certain proprietary fungicides, each preparation being applied alone and in combination with arsenate of lead. He reports self-boiled lime-sulphur as giving the most favorable results, his recommendations (p. 47) paralleling those of Scott and Ayres (1910).

Clinton and Britton (1911, p. 604–618) sprayed peaches with self-boiled lime-sulphur, potassium sulphid, and certain proprietary sprays. In certain applications, insecticides were added to the fungicides. These authors report most satistactory results from the self-boiled lime-sulphur and recommend its use.

Blake and Farley (1911, p. 11–30), in an extensive series of peach-spraying experiments, made comparative tests of home-boiled lime-sulphur, self-boiled lime-sulphur, and certain proprietary fungicides. They regarded all the preparations used except self-boiled lime-sulphur and a sulphur paste as too toxic to be applied with safety to peach foliage unless made too dilute to be efficient. They recommend the use of self-boiled lime-sulphur, which they state (p. 26) "is the best fungicide known at the present time for the control of peach scab and brown-rot."

Norton and Symons (1912, p. 266–268), in continuation of previous experiments, tested self-boiled lime-sulphur and various proprietary preparations in peach-scab control. They reported that self-boiled lime-sulphur gave the most favorable results.

These and like experiments appear to show (1) that Bordeaux mixture and various other copper sprays, lime-sulphur, and liver of sulphur, in combination with arsenate of lead, in concentrations sufficiently strong to control scab, are too toxic to be applied generally as summer sprays for the peach; (2) that peach scab may be controlled by spraying with self-boiled lime-sulphur, alone or mixed with arse-

nate of lead, without serious injury to the host; and (3) that sulphur paste may control this disease.

The purposes of the writer's experiments were (1) to test further, in relation to locality, season, and variety, the excellent spray schedules worked out by Scott and others; (2) to test the efficiency and desirability of a sulphur spray in comparison with self-boiled lime-sulphur; and (3) to correlate with control measures a clearer understanding of the nature, cause, and development of the disease.

The spraying experiments [1] were conducted in commercial orchards at Cornelia, Ga., in 1910, 1912, and 1913, and at Hart, Mich., in 1911. More than 150 plats, containing over 10,000 trees, were sprayed, while parallel observations were made upon commercial orchards containing in the aggregate many hundred thousand trees.

In the experiments of 1911, 1912, and 1913, the spray was applied by means of a gasoline power sprayer, double "Friend" nozzles being used. At Cornelia, in 1910, good barrel outfits were employed.

Careful field observations of each plat were recorded throughout the season. At harvest time, in as many cases as was feasible, the fruit from a number of typical trees of each plat, usually 10 to 12, was picked, critically examined, and classified according to the occurrence and abundance of scab, the occurrence of brown-rot, and the salability of the fruit. By carefully noting many thousands of fruits in this fashion and tabulating the resulting data, it was possible to arrive at strikingly accurate and concrete comparisons of the efficiency of the different treatments.

Experiments in 1910 and 1911.[2]

The season of 1910 in northern Georgia was very favorable for the development of scab and brown-rot and offered a severe test of the efficiency of the various treatments used. The results were eminently satisfactory, but since they have been reported in brief by Scott and Quaintance (1911, p. 23–26), they will not be considered further here.

In 1911 extensive experiments were conducted at Hart, Mich., on 10 of the more important commercial varieties of that section. Owing to an unusually dry spring and summer, so little scab occurred, even upon unsprayed trees, that little differentiation of results of the various treatments was feasible. Even under these conditions, however, the sprayed fruit appeared to be sufficiently superior to that of the control plats to justify the expense of the treatments. These results will not be considered further in this connection.

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[1] Grateful acknowledgments are made to Messrs. A. M. Kitchen, Cornelia, Ga. (1910), H. W. Gebhart and F. Brooker, Hart, Mich. (1911), A. B. Veeder, S. R. Christie, and Laing & Segers, Cornelia, Ga. (1912), and W. B. Hunter, Cornelia, Ga. (1913), for their cordial cooperation.

[2] These experiments were conducted under the direction of Mr. W. M. Scott, formerly Pathologist, Office of Fruit-Disease Investigations, Bureau of Plant Industry, U. S. Department of Agriculture.

Experiments in 1912.

TREATMENT.

A summary of the treatments of the individual plats and results therefrom is given in Table X. No plat contained less than 40 trees.

Table X.—*Summary of treatments and results in spraying experiments, Cornelia, Ga., 1912.*

Variety and plat.	Treatments.				Results.							
	Spray used.[1]			Dates of application.[2]	Count of trees.	Total fruits.	Scabbed—[3]				Culled.	Merchantable.
	First application.	Second application.	Third application.				Slightly.	Commercially.	Badly.	Total.		
							P. c.	P. c.	P. c.	P. c.	P. c.	P. c.
Carman:												
1	Al&lime...	Al&Sp....	Sp.....	(1) Apr. 30	10	5,598	7.3	0.2	0	7.5	5.5	94.5
2	...do.....	Al&S-b l-s.	S-b l-s...		10	7,941	8.2	.4	0	8.6	4.2	95.8
3	.....	...do.....	...do.....	(2) May 13-14								
4	Al&lime...	.....	...do.....									
5	...do.....	Al&S-b l-s.	.....	(3) June 1								
6	Control....	.....	.....		10	7,659	51.4	35.3	.9	87.3	22.7	77.3
Elberta:												
9	Al&lime...	Al&Sp....	Sp.....		10	2,396	39.7	3.4	0	43.1	2.5	97.5
9A	...do.....	...do.....	...do.....									
9B	...do.....	...do.[4]...	...do.[4]...									
10	...do.....	.....	Sp.....	(1) Apr. 23-24	10	5,791	45.1	52.2	.5	97.8	5.0	95.0
11	.....	Al&Sp.....	...do.....									
12	.....	Al&S-b l-s.	S-b l-s...	(2) May 15-16	6	3,294	65.4	6.2	.03	71.6	7.6	92.4
13	Al&lime...	.....	...do.....		10	5,937	47.4	49.2	1.2	97.8	8.3	91.7
14	...do.....	Al&S-b l-s.	...do.....	(3) July 2	10	7,620	63.3	5.5	.05	68.8	2.8	97.2
14A	...do.....	...do.....	...do.....									
15	Control....	.....	.....		11	4,400	32.7	63.1	3.1	98.9	31.6	68.4
15A	...do.....	.....	.....									
Belle:												
16	.....	Al&S-b l-s.	S-b l-s...									
17	Al&lime...	.....	...do.....	(1) Apr. 23	7	2,015	35.9	60.0	3.3	99.2	5.9	94.1
18	.....	Al&Sp....	Sp.....									
19	Al&lime...	.....	...do.....	(2) May 14								
20	...do.....	Al&S-b l-s.	S-b l-s...		7	3,239	68.5	7.2	.2	75.9	2.8	97.2
20A	...do.....	...do.....	Sp.....	(3) June 18								
21	...do.....	Al&Sp.....	...do.....		7	2,529	60.2	6.1	.03	66.3	3.7	96.3
22	Control....	.....	.....		7	2,077	24.6	71.2	3.3	99.1	9.3	90.7

[1] Abbreviations for sprays used: Al=Arsenate of lead paste (diplumbic), 1½ pounds in 50 gallons. Lime=Stone lime, 3 pounds in 50 gallons. Sp=A proprietary sulphur paste, 5 pounds in 50 gallons (except on plat 9B) a preparation consisting of finely divided sulphur (45 to 55 per cent sulphur guaranteed) with a small amount of organic adhesive material in suspension in water. S-b l-s=Self-boiled lime-sulphur, 8 pounds of lime and 8 pounds of sulphur in 50 gallons.

[2] The treatments were made, as nearly as feasible, (1) 10 days after the petals fell, (2) one month after the petals fell, and (3) one month before the fruit ripened.

[3] Slightly scabbed fruits included those bearing from one to a few scattered, inconspicuous spots; commercially scabbed, those sufficiently marred to detract from their market value but not to render them unmerchantable; and badly scabbed, those rendered nearly or wholly unmerchantable by excessive scab infection.

[4] Sulphur paste, 8 pounds in 50 gallons.

The condition of the experimental plats is briefly described as follows:

Plats 1–6.—Eight-year-old Carman trees, well grown, but badly neglected and suffering from lack of pruning, cultivation, and fertilization. Fertile clay-loam soil. Orchard elevated and slightly rolling, with excellent air and surface drainage. Had received an imperfect winter application of lime-sulphur. Fairly well pruned in early spring and cultivated throughout the season. Crop good.

This orchard, which had been practically abandoned, had just been bought for planting to apples. It was chosen as offering most adverse conditions for the production of good fruit and a most severe test of the efficacy of the treatments used.

Plats 9–15.—Vigorous, well-grown, well-kept, 8-year-old Elberta trees. Orchard elevated and slightly rolling, with excellent air and surface drainage. Sandy clay soil. Had received a winter application of lime-sulphur. Well pruned, cultivated, and fertilized. Crop good.

Plats 16–22.—Vigorous, 8-year-old Belle trees, well kept, but slightly under size. Sandy clay soil. Orchard elevated and slightly rolling, with good air and surface drainage. Had received the winter application of lime-sulphur. Well pruned, cultivated, and fertilized. Crop good.

RESULTS ON FOLIAGE.

Observations made at frequent intervals throughout the season showed no evidence of spray injury upon any of the plats treated with self-boiled lime-sulphur. In plats 9, 9A, 9B, and 11, however, sprayed with the sulphur paste and arsenate of lead, a considerable amount of "shot-holing" and yellowing of the foliage began to appear about the middle of July. This was followed by some defoliation throughout late July and early August. The fruit of these plats was very highly colored but not injured. The foliage of the parallel self-boiled lime-sulphur plats (12, 13, and 14) was not injured, being quite vigorous, well colored, and free from disease except for a limited amount of leaf injury which possessed the typical characteristics of peach bacteriosis (*Bacterium pruni* Smith). The foliage of the control plat, though less vigorous than that of plats 12, 13, and 14 and not so well colored, showed very little yellowing and defoliation. These facts strongly suggested that the trouble in plats 9, 9A, 9B, and 11 was some type of spray injury.

Inasmuch as each of the earlier treatments had been omitted from one or another of plats 9 to 15, conclusive data appear to be available. The key to the situation seems to lie in plat 10, which was treated in the same manner as the adjacent plats, 9 and 9A, except that the second application was omitted. On this plat, directly adjacent to plat 9, the foliage went through the season in excellent condition, closely approaching that of the self-boiled lime-sulphur plats in vigor and color. Thus, all plats (9, 9A, 9B, and 11) which received the sulphur paste and arsenate of lead in the second application were generally affected, while none of the remaining plats showed any evidence of spray injury. Therefore, it seems conclusive that the injury must have resulted from this treatment.

No experiments were made to test separately and comparatively the action of the sulphur paste and of arsenate of lead. However, since sulphur alone has proved to be one of the safest fungicides known and since the sulphur paste caused no injury when applied alone in the third treatment on plat 10, it seems evident that the

injury resulted from the arsenate of lead. Inasmuch as the second application, being the primarily important scab treatment, was quite heavy, this result is not surprising. The fact that no such deleterious results attended the use of arsenate of lead in combination with the self-boiled lime-sulphur indicates strongly that the addition of lime, as in the first application, would have prevented or minimized the injury. If the lime is necessary as a precautionary measure in the first application it would seem equally so in connection with the sulphur paste in the second.

Though, unfortunately, no plats in which lime was added to the arsenate of lead and sulphur paste in the second application were included in these experiments, the practicability of its satisfactory addition was shown clearly in an adjoining orchard. At the writer's suggestion, the addition of lime, at the rate of 2 pounds to 50 gallons, was made in the second application on the 30,000-tree orchard of the Habersham Orchard Co. In all other respects this orchard was treated similarly to plat 9. The foliage went through the season in excellent condition and the control of diseases was eminently satisfactory. However, the work was, of course, not experimental.

These observations on foliage injury are presented merely as field notes upon what appeared to be a clear case of arsenical injury. They are not set forth as warranting generalizations, but merely as a further warning that, as would be expected, very considerable injury may result under certain conditions from heavy applications of arsenate of lead (diplumbic) with sulphur paste. It should be clearly borne in mind, however, that there was no evidence to indicate that the injury was any greater than it would have been had the arsenate of lead been applied alone.

RESULTS ON FRUIT.

PLATS 1-6: CARMAN.

Results were taken at harvest time in the manner previously described, upon representative trees of plats 1, 2, and 6. In all cases the count trees were selected as typical of the plats which they represent. As it reached the proper stage for shipping, the fruit was gathered in successive pickings by the regular orchard employees, being thus harvested in the same manner and at as nearly as possible the same stage as the rest of the fruit of the commercial orchards. The fruit from each tree was picked separately and promptly turned over to the writer for examination. The records for each tree at each picking were thus kept separately throughout. The summarized results of this count work appear in Table X, while certain facts which can not be shown in tabular form are stated as follows:

Supplementary notes.—Under the conditions of these experiments, inasmuch as the plum curculio (*Conotrachelus nenuphar* Herbst.) injury, scab, and rot were considerably

less severe than usual, all the sprayed plats gave a commercially satisfactory control of these troubles. Plats 1 and 2, however, gave markedly superior results, yielding a quantity and quality of fruit which scarcely would have been credited as possible when the work was begun in the spring.

On plat 3, as would be expected, the insect injury was somewhat worse than on plats 1 and 2, while the scab on plat 4 was materially more apparent than on plats 1 and 2, though not quite so conspicuous as on the control.

On plat 5 scab and curculio were well controlled. Consequently, rot was not very abundant, though it developed to a rather serious extent during the severe conditions which obtained throughout the latter part of the harvest period, when daily rains occurred. The amount of rot which thus appeared was ample to justify the third application, as in the case of plats 1 and 2.

Striking though they are, the tabulated figures do not give a full conception of the real contrast between the sprayed and unsprayed fruit. The former was firm, uniform, and highly colored, passing excellently through the severe conditions of the picking season and carrying to market in good condition. The latter was much inferior in color, uniformity, and texture, ripening rapidly and unevenly, and becoming too soft for shipment unless picked green. The close picking of the control trees lessened the percentage of rot and culls, as the brown-rot fungus attacks the peach most severely after the fruit has entered well into the ripening stages.

These results show (1) that the sulphur paste and self-boiled lime-sulphur, respectively, controlled scab and brown-rot in a highly satisfactory manner, the fruit of plats treated with the two fungicides being of remarkably similar quality, agreeing almost to a per cent in each classification (plats 1 and 2); (2) that in northern Georgia at least two, and preferably three, applications are necessary for the satisfactory commercial spraying of the Carman and similar early varieties; (3) that the timing of the application on plats 1 and 2 was satisfactory; and (4) that the second application was primarily responsible for scab control.

PLATS 9-15: ELBERTA.

The summarized results from the more important Elberta plats appear in Table X. Certain data which can not be included in the table are as follows:

Supplementary notes.—The fruit of plats 9A and 9B was so similar to that of plat 9 and the results on plat 11 were so similar to those on plat 12 that no counts were made from plats 9A, 9B, and 11.

As in the case of the Carman results, the tabulated figures fail to give an adequate conception of the superiority of the sprayed over the unsprayed fruit. At first glance, it would seem, for instance, that a very considerable amount of scab infection had taken place on the sprayed fruit. Such, however, was not the case, the great majority of sprayed fruits classified "slightly scabbed" bearing only one to several small, inconspicuous infections which could be detected only by critical expert examination. Thus, a single scab spot of this type frequently served to classify an otherwise perfect fruit as "slightly scabbed." On the other hand, in the case of the unsprayed fruit, the "slightly scabbed" specimens usually bordered very closely upon the "commercially scabbed" class. Therefore, it is important to note clearly that the scab infection on the fruit of all plats which received the second application was commercially negligible.

These results show (1) that the sulphur paste and self-boiled lime-sulphur, respectively, controlled scab in a highly satisfactory manner and with remarkably similar results (plats 9, 14, and 15); (2) that the omission of the first application materially increased the amount of insect injury and diminished the amount of merchantable fruit (plats 11 and 12); (3) that the second application was, as indicated by previous field experiments and subsequent laboratory studies, primarily responsible for scab control (plats 9, 10, 13, 14, and 15); (4) that in northern Georgia three applications of spray are necessary for the satisfactory commercial control of scab, rot, and the curculio upon the Elberta and similar midseason varieties; (5) that the sulphur paste at the rate of 5 pounds in 50 gallons was in sufficiently strong dosage, giving apparently as good results as 8 pounds in 50 gallons used comparatively (plats 9 and 9B); and (6) that the timing of applications on plats 9 and 14 was satisfactory.

PLATS 16–22: BELLE.

The summarized results from the more important Belle plats are given in Table X. Certain data which can not be incorporated in the table are as follows:

Supplementary notes.—Plats 16 and 18 when carefully noted at harvest time were indistinguishable in their results from plats 20 and 21, respectively, except for the prevalence of a considerable amount of superficial insect injury. Owing to the unusually light attack of the curculio, the omission of the first application was thus attended by very little loss. This condition, however, appears to be quite unusual for the section, and these results do not justify the risk of omitting this treatment in commercial orchards.

The results of plats 17 and 19 were so similar at harvest time that counts were made from plat 17 only. A like similarity occurred in the cases of plats 20, 20A, and 21, results being taken from 21 only.

These results show (1) that the sulphur paste and self-boiled lime-sulphur, respectively, controlled scab in a highly efficient degree and with remarkably similar results (plats 20 and 21); (2) that the omission of any one of these three applications would have been unwise (plats 16, 17, 18, and 19); (3) that the second application was primarily responsible for scab control (plats 17, 19, 20, 21, and 22); (4) that in northern Georgia three applications of spray are necessary for satisfactory commercial results on the Belle and similar midseason varieties; and (5) that the substitution of the sulphur paste for self-boiled lime-sulphur in the third treatment on plat 20A in nowise lessened the efficiency of the schedule, the substitution having the advantage of precluding the possibility of spray-stained fruit at harvest time.

THE SPRAY SCHEDULE.

While this discussion is concerned primarily with peach-scab control, it must consider incidentally the control of brown-rot and the

plum curculio, since in the more important peach-producing sections of the United States east of the Rocky Mountains any commercially successful scab treatment must combine satisfactorily and economically with control measures for these associated troubles.

THE TIME AND NUMBER OF APPLICATIONS FOR MIDSEASON VARIETIES.

Treatment before the blossoming period.—Numerous writers have recommended as the first spray for scab a treatment just before the blossoming period. Sturgis (1897, p. 271), apparently on a priori grounds, suggested this treatment, while Selby (1904, p. 66) includes it in his recommendations. His tabulated results (1898, p. 251–252), however, show no decisive benefit resulting from this application, while, on the other hand, his best control in certain cases occurred on plats which did not receive this treatment. Evans (1911) and others make like recommendations. Scott (1907, 1908, and 1909), Scott and Ayres (1910), Scott and Quaintance (1911), and others showed that scab can be successfully controlled when this winter application is omitted. Clinton and Britton (1911, p. 614; 1912, p. 374) concluded from comparative experiments that this treatment had little or no effect upon scab or rot. They (1912, p. 374) state—

> In 1910, all of the trees having this winter treatment gave just as high a percentage of scab * * * as did those not having it, neither lot having any summer treatment. In 1911, all the trees having this winter treatment and three summer treatments did not give any lower percentage either of scab or rot than those that received only the three summer treatments.

Furthermore, the writer's life-history studies previously reported show that at the time of the winter treatment the fungus is so well protected by the cuticle of the host that it would not be feasible to combat it efficiently with any standard fungicide. It appears conclusive, therefore, that a winter application is not necessary for efficient scab control.

Treatment as calyces shed.—Clinton and Britton (1911, p. 614, 617) recommend the application of a suitable fungicide at about the time the calyces are shed. Their data (p. 614), however, do not show any better results from this application in conjunction with two later treatments than from the later treatments alone, and these authors (1912, p. 395) suggest that if any of these applications must be omitted it should be the first. Blake and Farley (1911, p. 19) reported that scab development was considerably checked, though by no means controlled, by a single application of a suitable fungicide when the calyces were being shed. They recommended (p. 26) this treatment in conjunction with two later applications. They did not, however, give a thorough test to the two later treatments alone, using self-boiled lime-sulphur or a sulphur spray. Selby's (1898, p. 251) tabulated data, on the other hand, show no benefit from this

treatment. Selby (1904), Scott (1909), Scott and Ayres (1910), Scott and Quaintance (1911), and others showed conclusively that scab may be controlled to a degree which is entirely satisfactory commercially when the first fungicidal treatment is made about one month after the petals fall. The results of the writer, previously reported, offer further confirmation of this work. When the application is delayed so long as this, slight scab infection is to be expected, but it is usually confined to scattered, inconspicuous lesions about the peduncles. It appears conclusive, therefore, that the application of a fungicide at the time of the shedding of the calyces is not necessary to commercially satisfactory scab control, except possibly under very extreme conditions, though at times it may be of some value, and is relatively inexpensive when an application of arsenate of lead is made for the plum curculio at this time.

Treatment about one month after petals fall.—The results of Selby (1898 and 1904), Scott (1908 and 1909), Scott and Ayres (1910), Clinton and Britton (1911), Scott and Quaintance (1911), Blake and Farley (1911), and others indicate the importance of the application of a suitable fungicide about one month after the petals fall. The results of the writer (plats 9, 10, 13, 14, 15, 17, 19, 20, 21, and 22) further confirm this work, showing clearly that for midseason varieties this is the primarily important treatment for scab.

Treatment three to four weeks before the fruit is harvested.—The work cited in the preceding paragraph indicates the desirability of a further fungicidal treatment. If scab only were considered this would be made about two or three weeks after the preceding application, since previously reported life-history studies have shown that infections which occur later than six weeks before the fruit is harvested are not likely to become injurious. However, the fact that this treatment must, for the sake of economy, serve also as the final spray for brown-rot makes it necessary to delay it until three weeks or a month before the fruit is picked.

VARIATION OF SCHEDULE FOR EARLY VARIETIES.

The results of Scott and Ayres (1910), Scott and Quaintance (1911), the writer (plats 1, 2, 5, and 6), and others show that on early varieties commercially satisfactory scab control may be effected by a single thorough fungicidal treatment about one month after the petals fall and that under certain circumstances the later treatment may be omitted without serious loss of efficiency. In such cases the first and second treatments, as recommended for midseason varieties, will suffice. In cases where there is danger of serious outbreaks of brown-rot, however, the omission of the third application seems unwise. In such cases the three applications, as recommended for midseason varieties, should be made.

VARIATION OF SCHEDULE FOR LATE VARIETIES.

Scott and Quaintance (1911) showed clearly that while the treatment recommended for midseason varieties will go far toward controlling scab on highly susceptible late varieties, the addition of an application of the fungicide alone four or five weeks after the second regular treatment, or about eight or nine weeks after the petals fall, may materially increase the efficiency of scab control and thoroughly justify itself economically.

THE FUNGICIDE TO USE.

The first and most difficult requisite of a satisfactory fungicide for the summer spraying of peaches is that it must not be seriously injurious to the host, whether applied alone or in conjunction with a satisfactory internal poison for insects. Furthermore, of course, the spray must be efficient, cheap, and reasonably easy to prepare and apply, and it must not leave seriously objectionable residues upon the fruit at harvest time. From the work of Sturgis (1901), Bain (1902), Scott (1907 and 1908), Lewis (1910), Clinton and Britton (1911 and 1912), Blake and Farley (1911), Norton and Symons (1912), and others, it is clear that Bordeaux mixture, soda Bordeaux, ammoniacal copper carbonate, copper subacetate, potassium sulphid, home-boiled lime-sulphur, and various proprietary preparations of copper, sulphur, and lime-sulphur, in concentrations to be economically efficient, have failed to meet the first of these requirements and are not to be recommended, save possibly under very exceptional conditions, for the summer spraying of peaches. The work of Scott (1907, 1908, and 1909), Scott and Ayres (1910), Lewis (1910), Clinton and Britton (1911 and 1912), Scott and Quaintance (1911), Blake and Farley (1911), Norton and Symons (1912), the writer (plats 2, 6, 14, 15, 20, and 22), and others shows conclusively that self-boiled lime-sulphur, properly prepared and applied, will meet all of the requirements mentioned above and will satisfactorily control peach scab. Clinton and Britton (1912, p. 373–375) report that in their experiments a proprietary sulphur paste controlled peach scab as well as did self-boiled lime-sulphur, but that in certain cases when it was applied with arsenate of lead serious foliage injury resulted. They were inclined to believe, however, that this injury resulted from the insecticide. Blake and Farley (1911, p. 22) reported promising results from the use of the same sulphur paste in combating peach scab, but their experiments were not sufficiently extensive to justify conclusions. Norton and Symons (1912) sprayed peaches with this fungicide, but reported (p. 268) that the results obtained were too variable to be conclusive. The writer's results (plats 1, 2, 6, 9, 14, 15, 20, 21, and 22) indicate that sulphur paste, properly applied, will control peach scab as efficiently as will self-boiled lime-sulphur and

may be used with safety as a summer spray for peaches either alone or with arsenate of lead. In the latter case, however, the same precautions should be taken against arsenical injury that are observed when the lead arsenate is applied alone. It is altogether probable that thorough applications of finely divided sulphur of any type will control peach scab.

From this evidence, the writer recommends for peach-scab control (*a*) self-boiled lime-sulphur (8–8–50) and (*b*) finely divided wettable sulphur. With the paste (approximately 50 per cent sulphur) used in the experiments previously reported, 5 pounds in 50 gallons is a satisfactory dosage. These sprays appear to be equally efficient. Self-boiled lime-sulphur is in most sections the cheaper, while wettable sulphur is somewhat easier to apply and leaves a less conspicuous residue upon the fruit. The cheapness of self-boiled lime-sulphur and its efficacy in preventing or diminishing injury from arsenate of lead make it very satisfactory for the first fungicidal application, while the fact that the wettable sulphur leaves little stain upon the fruit makes that the more desirable for the final treatment. While for many cases this combination of the two sprays appears to be the most desirable, the final choice should be made by the individual grower in the light of these facts and of his own needs and preferences.

Cost of Treatment.

Selby (1898, p. 260), working in Ohio, estimated that the cost of spraying peach trees was less than 1½ cents per tree for each application in foliage. Scott and Ayres (1910, p. 21) reported that with a power outfit in Georgia they were able to make four applications of summer spray, two containing arsenate of lead (2–50) and three containing self-boiled lime-sulphur (8–8–50) for 5⅗ cents per tree. The trees were medium-sized 7-year-old Elbertas. These authors considered that under southern conditions three applications should be made for 4½ cents per tree. Blake and Farley (1912, p. 70–71), working in New Jersey with a hand outfit, reported making four summer applications, two containing arsenate of lead (2–50) and three containing self-boiled lime-sulphur (8–8–50) on 5-year-old Elbertas for 5.59 cents per tree. The writer, working under the direction of Mr. W. M. Scott at Cornelia, Ga., in 1910, kept accurate records of the cost of spraying with a hand outfit. These data, which are reported more in detail by Scott and Quaintance (1911, p. 38), show that the cost of three applications, two containing arsenate of lead (2–50) and two containing self-boiled lime-sulphur (8–8–50), on 7-year-old trees was 2.76 cents per tree. The conditions for this work, however, were unusually favorable. At Fort Valley, Ga., where a power outfit was used, but where other conditions were less favorable than at Cornelia, the cost of similar treatments, as reported by the same

authors, was 3.2 cents per tree. These writers state (p. 38) that for these three treatments the cost will range from 3 to 5 cents per tree, depending upon the labor conditions, the size of the trees, the convenience of the water supply, and the equipment used. While in certain sections where labor is exceptionally expensive the cost may somewhat exceed these figures, this estimate appears to be sound.

Profit from Treatment.

The profit from spraying appears in the increased amount, the superior quality, the better keeping and carrying properties, and the enhanced market value of merchantable fruit. Scott and Ayres (1910, p. 19–20), working in Georgia, report that from Elbertas which were sprayed four times the yield of merchantable fruit was ten times that from similar unsprayed trees. By marketing tests they showed, further, that the sprayed fruit from this block sold for 50 cents per crate more than the fruit from the unsprayed trees. Scott and Quaintance (1911, p. 31) report further shipping tests in which sprayed Elbertas sold for 75 cents a crate more than similar unsprayed fruit of the same variety shipped in the same car. Blake and Farley (1911, p. 30) state that the profit secured by spraying at Vineland during the season of 1910 was more than $1.50 per tree, while the cost of applying the most expensive treatment did not exceed 5 cents per tree. In the experiments conducted by the writer at Cornelia, Ga., in 1910 and reported in part by Scott and Quaintance (1911, p. 23–26), 70 Elbertas (p. 24) which had received three applications of spray, as recommended later, yielded 97.04 per cent of merchantable fruit, while on 70 parallel unsprayed trees only 54.11 per cent of the crop was merchantable. The yield of similarly treated Summerours (p. 25) was 85 per cent merchantable, as compared with 6.49 per cent from the similar unsprayed trees. An additional application on this variety, as recommended later, would have been necessary for a more thorough control of scab and rot. The actual yields in merchantable fruit from 70 representative trees from each of these plats were 113 bushels from sprayed Elbertas, 31.2 bushels from unsprayed Elbertas, 115 bushels from sprayed Summerours, and 3.5 bushels from unsprayed Summerours.

The previously reported results obtained by the writer at Cornelia, Ga., in 1912 show that even in a season when fungal and insect injuries were less serious than usual, the standard spray treatments, as recommended later, increased the percentage yield of salable sprayed fruit, as compared with unsprayed, 17.2 to 18.5 per cent in the case of the Carman, 28.8 to 29.1 per cent in the case of the Elberta, and 6.5 per cent in the case of the Belle, which escaped disease in an unusual degree.

These results show that where brown-rot, scab, and the curculio are serious factors, spraying is not only highly profitable, but that it is indispensable to commercial success.

Recommendations for Spraying.

SCAB ONLY.

Early varieties.—Spray with self-boiled lime-sulphur, 8–8–50, or wettable sulphur, 5 pounds in 50 gallons in the case of the paste (approximately 50 per cent sulphur) used in the foregoing experiments, about one month after the petals fall.

Midseason varieties.—Spray as for early varieties, adding a similar application about three weeks later.

Late varieties.—Spray as for midseason varieties, adding a third application about one month after the second.

SCAB, BROWN-ROT, AND THE PLUM CURCULIO.

In practice it is rarely desirable to spray for scab alone, since in most sections where scab is seriously injurious brown-rot and the plum curculio must also be combated. In order to secure the most profitable combination treatment, therefore, certain deviations must be made from the ideal individual schedules, while modifications must be made to meet the needs of sections, seasons, and varieties. Recommendations for the control of brown-rot and the curculio are, consequently, inseparable from those for scab, and, though incidental to this paper, must be included. The recommendations for brown-rot are based upon the results of Scott (1907, 1908, and 1909), Scott and Ayres (1910), Scott and Quaintance (1911), and others, and upon unpublished results of the writer. That part of the schedule which relates to insect control has been kindly supplied by Mr. A. L. Quaintance, of the Bureau of Entomology, United States Department of Agriculture.

While for obvious reasons ironclad recommendations are not attempted, the following schedule, subject to intelligent modification,[1] should be applicable in most commercial peach sections of the United States where scab is a serious factor.

Early varieties.—The early varieties, such as the Greensboro, Carman, Hiley, and those with similar ripening periods should be sprayed as follows:

(1) With arsenate of lead and lime about ten days after the petals fall. This application may be omitted in sections where the curculio is not a serious factor.

(2) With arsenate of lead and self-boiled lime-sulphur or finely divided wettable sulphur about a month after the petals fall. If the latter type of fungicide is used, the addition of lime, as in the first treatment, may be a desirable precaution against arsenical injury.

[1] For suggested modifications, see Scott and Quaintance (1911, p. 38–40).

(3) With finely divided wettable sulphur or self-boiled lime-sulphur three to four weeks before the fruit ripens, but not less than four weeks before harvest if self-boiled lime-sulphur is used. This application may be omitted in sections where brown-rot is not seriously injurious.

Midseason varieties.—The treatment recommended for early peaches is applicable, likewise, to midseason varieties, such as the Reeves, Belle, Early Crawford, Elberta, Late Crawford, and Fox. For such varieties, however, the third application is very essential and should not be omitted where brown-rot or scab injury is serious.

Late varieties.—The Salway, Heath, Bilyeu, and varieties with similar ripening periods should be treated as midseason varieties, with the addition of an application of the fungicide alone about a month after the second treatment.

The following concentrations of spray preparations are recommended: Arsenate of lead paste, 1½ pounds (powder, three-fourths pound) in 50 gallons; stone lime, 2 to 3 pounds in 50 gallons; self-boiled lime-sulphur, 8 pounds of lime and 8 pounds of flour of sulphur in 50 gallons; and finely divided wettable sulphur, 5 pounds in 50 gallons in the case of the paste (approximately 50 per cent sulphur) used in the foregoing experiments. Directions concerning the preparation and use of these sprays are given by Scott and Quaintance (1911, p. 33–35).

ORCHARD SANITATION.

While the disposal of orchard refuse is a highly commendable practice and thoroughly justifiable from the standpoint of the control of other diseases, it appears to be of relatively slight importance in peach-scab control, since the lesions on the living twigs constitute the chief source of infectious material. Though it has been recommended that the diseased twigs be pruned out and destroyed, this procedure is manifestly impracticable in view of (1) the great numbers and inconspicuous appearance of the lesions and (2) their occurrence on the fruiting wood. Furthermore, such drastic measures are unnecessary, since the disease is readily and inexpensively controlled by spraying, and little or no injury is done to the affected twigs. Less directly, however, sanitation may be practiced with profit in pruning and growing the trees in such fashion as to facilitate the free access of air and sunlight and in providing for as good air and surface drainage of the orchard as is feasible.

RESISTANT VARIETIES.

Since the severity of scab injury varies materially with varieties, it should be remembered that the disease may be in some degree avoided by growing those varieties which are less severely attacked. However, inasmuch as these are chiefly the earlier peaches, it is not feasible to accomplish very much with this method in practice.

Furthermore, since even on the worst affected varieties the disease may be efficiently and economically controlled by spraying, the use of varieties which are in some degree disease escaping or resistant is unnecessary, though advisable when other factors are equal.

SUMMARY.

Peach scab (*Cladosporium carpophilum* Thüm.) manifests itself in serious spotting and cracking of the fruit and superficial injuries on twigs and leaves.

In the United States the disease has been reported from 34 States, which include practically every important peach-producing district east of the Rocky Mountains. Its occurrence has also been recorded in Austria, Canada, Holland, Australia, southern Europe, and South Africa.

Among the fungous diseases of the peach in the United States east of the Rocky Mountains, scab ranks next to brown-rot in economic importance. In many sections, before satisfactory control measures were developed it rendered unprofitable the growing of certain valuable commercial varieties. Unless controlled, it would be a serious menace to successful commercial peach culture in many of the most important peach-producing districts of the Southern, Eastern, and Central States.

The peach-scab fungus was first described by Von Thümen (1877), who assigned it the binomial *Cladosporium carpophilum*. Oudemans (1901) described as *Fusicladium carpophilum* Oud. a fungus growing on fallen young peaches. He lists as a synonym *Cladosporium carpophilum* Thüm., but neither gives Von Thümen credit for the specific name nor states his reasons for transferring the fungus to the genus Fusicladium. Aderhold (1901) expressed the belief that *C. carpophilum* Thüm. and *C. cerasi* (Rbh.) Aderh. are identical, but he admittedly failed to adduce sufficient evidence to justify this conclusion. Until further evidence is presented, the writer accepts the name *Cladosporium carpophilum* Thüm. for the peach-scab parasite.

The primarily important diagnostic characters of the fungus are the short, erect, more or less flexuous, one to several septate, rarely branched, olivaceous conidiophores and the ovate-fusiform, obtuse to apically subacute, continuous or 1-septate, light fuscous conidia, which are borne acrogenously, singly or in simple or branched chains.

The fungus was isolated from peach fruit, twigs, and leaves, respectively, in single-spore strains, which were grown comparatively upon more than 30 media. The cultural differences between strains from different organs of the host were no greater than those observed in strains from the same organ. The fungus grew well upon this wide range of media and showed only minor variations upon the different substrata.

Moisture favors growth. Desiccation checks growth and favors the formation of chlamydospores.

The minimal temperature for growth on favorable nutrient substrata is less than 2°; the optimal, between 20° and 27°; and the maximal, about 32° C.

Strong diffuse light favors sporulation.

Normal spores germinate readily in sterile distilled water, rain water, and a large variety of nutrient solutions and agar preparations. The alternate wetting and drying of germinating spores do not appear to be seriously injurious unless the changes are very frequent during the early stages of germination.

The minimal temperature for germination in water or in a favorable nutrient solution is less than 2°; the optimal, between 20° and 27°; and the maximal, slightly above 32° C.

Peach fruit, twigs, and leaves were inoculated with single-spore strains of *Cladosporium carpophilum* from peach fruit, twigs, and leaves, respectively. Each strain produced typical infection upon fruit, twigs, and leaves, with the exception of the leaf strain upon the fruit. In this case the experimental fruits were destroyed by trespassers before the results were available. Each strain of the fungus was repeatedly reisolated and was found to possess the typical morphological and cultural characters of *C. carpophilum*. Fruit infection was induced by direct inoculation with scrapings from abundantly sporulating twig lesions. Conclusive positive results from inoculations with *C. carpophilum* have not been previously reported.

Scab infection ordinarily appears shortly prior to the ripening period of early varieties and may continue throughout the season.

Spore production from fruit, twig, and leaf lesions may begin as soon as infection becomes macroscopic and may continue throughout the development of the lesions. The most abundant sporulation occurs on overwintered twig lesions during the spring and early summer following infection.

Freshly produced, normal conidia from fruit, twig, or leaf lesions are capable of germinating in sterile distilled water, rain water, or a variety of nutrient media.

When dry the conidia persist tenaciously upon their sporophores. In water, however, they quickly become detached. Meteoric water appears to be the most important agent in their liberation and dissemination.

In the inoculation experiments the period of incubation of the fungus upon the fruit was observed to vary from 42 to 77 days. Upon twigs and leaves it varied from 25 to 45 days. In nature the variations are undoubtedly even greater.

Little natural infection occurs until four to six weeks after the petals fall. Subsequently, under favorable conditions it rapidly becomes more abundant and may continue throughout the season.

Primary infection results from conidia from overwintered twig lesions. Spores from lesions of the current year's production may induce secondary infection.

The fungus overwinters in the mycelial stage in the lesions on living twigs. There is no evidence that any other type of overwintering is of any practical importance in the life history of the parasite, although it has been shown that the mycelium may survive the winter on fallen fruit and twigs.

Peach scab occurs at its worst in temperate sections where the spring and early summer are moist and the growing season is long. It is much less prevalent in dry sections and in high altitudes where the opposite conditions obtain.

Varieties vary markedly in the degree to which they are subject to scab injury. In general, early varieties are not very seriously affected. Midseason varieties may be moderately or severely attacked. Late varieties are usually the most severely affected. The period of exposure of the fruit to the attack of the fungus is a major factor in these differences. There are, however, varietal differences which are independent of the ripening period of the fruit. These have not been explained.

It has been shown conclusively that the disease may be controlled in a highly satisfactory manner by spraying with self-boiled lime-sulphur or with finely divided wettable sulphur and that the scab treatment may be satisfactorily combined with the control of brown-rot and the plum curculio. (For summarized recommendations, see pp. 59–60.)

Under average conditions, the cost of spraying 7-year-old to 10-year-old peach trees for scab, brown-rot, and the plum curculio (three treatments, as recommended on pp. 59–60) should not exceed 5 cents a tree.

In the writer's experience, the merchantable fruit from trees properly sprayed in accordance with the foregoing recommendations has rarely amounted to less than 95 per cent of the total yield, even under severe conditions, while its quality has uniformly been much superior to that of the unsprayed product.

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